70(8A): 1-479; 2022. DOI: 10.18311/jmmf/2022/31978

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Investigations on IC Engine Piston Ring made of Composite Materials

Ankit Gupta*[1], Ashok Atulkar[2], Rajkumar Porwal[3]

*[1]Department of Mechanical Engineering, SGSITS, Indore, M.P., India. e-mail: ankit.gupta032@gmail.com[1]
[2]Department of Mechanical Engineering, SGSITS, Indore, M.P., India. e-mail: ashokatulkar@gmail.com[2]
[3]Department of Mechanical Engineering, SGSITS, Indore, M.P., India. e-mail: rajkumarporwal@gmail.com[3]

Abstract

This paper is respecting the evaluation of stress distribution on IC engine (four-stroke) piston ring and analysis of finite element by using FEA software. The purpose of this analysis is to calculate strain for SiC reinforced ZrB2, A360, A2618 and deformation resulting through ring elastic pressure and gas pressure. The total deformation and strain on the piston ring have been obtained in this project. The characteristics of such vibrations are analyzed with the help of solid works software and analysis of finite element is performed on the Ansys workbench software. The material used is Silicon Carbide reinforced Zirconium Diboride (SiC reinforced ZrB2), Aluminium alloy (A360), Aluminium alloy (A2618). This is a ceramic matrix composite (CMC) which has good safety factor and lower cost. The experiment is conducted on three types of composites to evaluate the strain on SiC reinforced ZrB2, A360, A2618 resulting from the total deformation and strain. Compressive strength has also been analyzed for the structural model of the piston ring.

Keywords: *Piston ring, Finite element analysis, SiC reinforced ZrB2, A360, A2618*

1.0 Introduction

Thermal analysis and structural analysis of the piston ring are deliberated in order to find out the stress that the ring can bear. The structural analysis determines the effect of loads on the piston ring. Physical structures and thermal analysis result in the variation of physical properties, and a substance is measured as a temperature function. They observed that, as fuel consumption goes down, the overall efficiency of the engine increases [1] [6] [7] [12]. The first and second sealings of the piston ring fill the gap between the piston and the cylinder, thereby reducing gas leakage [2] [14] [15] [19]. Simulation of a piston ring using a multibody single cylinder internal combustion engine using clear finite elements. The solid geometry was created with the help of the SDRC IDEAS package. The finite element method is used for simulation. Piston secondary motion is studied, and this serves as input to gate possible revision of information via piston skirt geometry to reduce friction and engine noise. [3]. In this paper, I observed that the coating surface of the piston ring protects the piston ring against thermal and mechanical effects during friction. Plasma spray technology is used in this research, and salt spray testing is a standardized method used to test the corrosion resistance of coated specimens and to investigate the tribological properties under dry friction conditions for aluminium plasma-sprayed nanostructured zirconia coatings compared to traditional zirconia coatings [4]. Various mechanical analyses were conducted and the wear effect with different percentages of alumina reinforcement was studied and used for the stir casting technique, a conventional metal-forming technology [5]. The displacement and stress are analyzed by using Ansys

*Corresponding author

and applying pressure to the piston or piston ring and comparing the different materials for analysis to find out which material is better for manufacturing the piston or piston ring [8]. The thermal and structural stress distribution of the piston ring is determined using the finite element method. By this, it is noted that the stress of the composite ring is within allowable limits and the natural frequency of the ring is reduced because of the reduced weight of the ring [9] [10] [21]. Checking the thermal slope, stress, and reviewed designs using the Ansys software. The additional thermal assessment and architectural assessment is done with the help of pressure and temperature in different stages. The strain, stress, and deformation values for steel are lower than for CI and aluminium alloy, according to the analysis performed on various materials. [11] [13]. Hypereutectic alloys can be used as piston materials instead of the commonly used alloys of aluminium, cast iron, AlSiC, Al_2O_3, etc. We have performed the structural and static thermal analysis at ANSYS to determine the properties of AlSi17Cu5MgNi (hypereutectic alloy). Demonstrated durability and toughness can be used in engines with high performance. Current research on piston materials such as cast and forged aluminium alloys offers improved potential for optimization [16]. Thermal stresses and stress distribution of various aluminum alloy pistons using the finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature, and physical properties of the piston. This analysis shows less deformation of AlSiC graphite as compared to other composite materials by reducing the inertia force, good FOS, less weight, and higher strength for Al-GHS 1300 [17] [20]. The heat transfer method used to perform the thermal and numerical analysis is the 4-Ring articulated piston of a marine diesel engine. The secondary motion of the piston ring and piston with the lubricating oil film has been considered in estimating the coefficient of heat transfer values. The result of the experiment showed an increase in the temperature in the low-temperature region and a decrease in the maximum value in the high-temperature region [18]. The designed piston is analyzed for stresses in static structural, the life of the piston in fatigue analysis and total heat flux in thermal analysis of Ansys software. Hiduminium material shows better-optimized values in total heat flux as compared to other materials [22]. The tensile properties of A360 al alloy or ZrB2 particles for metal matrix composites. Industrial investigations are widely used for the latter method because of its net-shape forming capability or low cost [23]. In situ reinforced aluminium-based metal matrix composites using master alloys as reinforcement materials and attempted to explore the characterization or processing. Improvement in mechanical properties and good tensile strength for Al 6061-TiB2 in situ composites as compared to the base alloy [24]. Tensile strength, wear resistance and corrosion are those of matrix alloy. It is used to fabricate aluminium alloy AA6061 reinforced with ZrB2 particles [25]. The stress distribution on the piston surface, pressure is due to high temperature and pressure. The highest pressure occurred on the top section and a pedestal of the piston pin hole with higher total deformation as compared to the piston ring hole [26]. Static structural analysis of two stroke single cylinder engine piston is done. Dynamic analysis stress results or static analysis stress results are less than from the permissible stress value [27]. To determine the coupled thermal-mechanical, thermal, mechanical stress or temperature field of a 2-stroke 6S35ME marine diesel engine piston. The minimum temperature of lowest part of the piston crown is 323K, and the maximum temperature of top region of the piston is 660K. The mechanical stress is lower than the thermal stress [28]. It absorbed the total heat flux of the aluminium alloy piston or grey cast iron piston. The usage of cup or concave shaped pistons in IC engines is used for large sized engines or diesel as fuel because the total deformations and stresses observed in convex shaped piston are smaller than the concave shaped piston [29]. Thermal or structural analysis of the AlSiC material piston, as well as a comparison of aluminium thermal conductivity, temperature performance stiffness-to-weight, and hot strength coefficient of expansion for two different materials. Composite material piston has less stress, minimum total deformation and good temperature distribution compared to aluminium piston [30].

1.1 Objective

- To investigate stress with the help of stress analysis by Ansys software.
- To investigate total deformation using stress analysis by Ansys software.
- This project is based on analyzing the failure of piston rings and comparison of piston rings using both types of composites.

2.0 Methods and material

Cast Iron: This is the most commonly used material that retains the integrity of the original shape under load, heat and other dynamic forces. In earlier years, cast iron was the universal material for a piston ring as it passed excellent wear quality checks, had a high coefficient of expansion and was suitable for manufacture. However, the time required for the reduction of weight in the piston ring, for which SiC reinforced ZrB2, A360, A2618 became essential to obtain the required strength. But some of the advantages of the light metal were lost. SiC reinforced ZrB2 is inferior to cast iron in strength and wear properties, has a higher coefficient of expansion and has a greater clearance in the cylinder to avoid the risk of seizure. ZrB2 has greater heat conductivity than cast iron, which when combined with greater thickness and aluminum alloy, gives strength, and enables the piston ring to operate at much lower temperatures than cast iron. This coolness of SiC reinforced ZrB2 is now recognized as quite valuable as much as its lightness. Indeed, the piston ring is sometimes made thicker than necessary for strength to give better cooling. Usually, the piston rings are manufactured in steel or cast iron.

2.1 Problem definition and methodology

In this paper, FEA is used to evaluate the stress distribution on the engine piston ring for performing finite element analysis. The materials used in this project are SiC reinforced ZrB2, A360, A2618. The total deformation and strain made by the piston ring have been obtained and analyzed its characteristics using CAD Solid Works Software. Furthermore, the finite element analysis has been performed using the software Ansys.

The following steps are taken for performing analysis:

- Developing a 3D model using available 2D drawing of the piston ring.
- Creation of a 3D model with the help of Solid Works Software.
- The 3D model is imported to Ansys after converting it into Parasolid so that stress field analysis can be performed.
- Performed stress analysis on the piston ring model for SiC reinforced ZrB2, A2618, A360.
- Plotting stress distribution from the stress analysis for composite material.
- Body loads and working pressure 13.65 MPa are applied for structural analysis to finalize the stress distribution due to structural loads for composite material.
- Plotting deflection and stresses for the piston ring from the above analysis.
- Performing model analysis for SiC reinforced ZrB2, A2618, A360 composite material and the result is being explained.
- Model analysis has been performed for all three materials.

2.2 Modeling and analyzing of piston ring design

The piston ring has been designed as per the procedure and specifications are given in the "Machine Design and Data" handbook. Dimensions are calculated in terms of SI units. The parameters applied pressure, tension, length, the diameter of the piston ring, etc. are taken into account.

A: Design consideration for a piston ring: Following points should be noted while designing a piston ring for an engine: The piston ring should:

- Has great strength to withstand high pressure.
- Be the minimum load to withstand inertial forces.
- Provide sufficient bearing area to prevent improper wear.
- Have high-speed interactions without noise.
- Having a construction rigid enough to withstand mechanical delivery.

B: Ansys: Ansys is an FEA software. FEA is a numerical method that deconstructs a complex system into small elements. It implements equations to govern the behaviour of such elements and solve them. These results are presented in tabulated or graphical forms.

2.3 Properties of Material

The material selected for this work is SiC reinforced ZrB2, A360, A2618. Below testing processes are performed on the piston ring;

- The static analysis: Discussed in the analysis software.
- The below list (Table 1 and 2) mentions the mechanical properties of composite material.

Table 1: Volume percent of SiC reinforced ZrB2

Material	SiC wt %	ZrB2 wt %
10%wtSiC+90%wtZrB2	10	90
20%wtSiC+80%wtZrB2	20	80
30%wtSiC+70%wtZrB2	30	70

2.4 Meshing of Piston ring model

After allocating material properties, opened the model in mechanical. The piston body has been selected and performed Meshing. 1 mm-sized tetrahedral elements have been used. The mesh for the piston ring is generated for SiC reinforced ZrB2, A2618, A360.

	Name of Property	SiC reinforced ZrB2	A360	A2618	Cast iron
Table 2: Material Properties of Piston ring					
1	Density, (kg/m^3)	2060	2650	2767.9	7810
2	Young Modulus, (GPa)	486	71	73.7	150
3	Ultimate Strength, (MPa)	1070	300	480	900
4	Yield Strength, (MPa)	930	180	420	600
5	Poisson Ratio	0.11	0.33	0.33	0.37

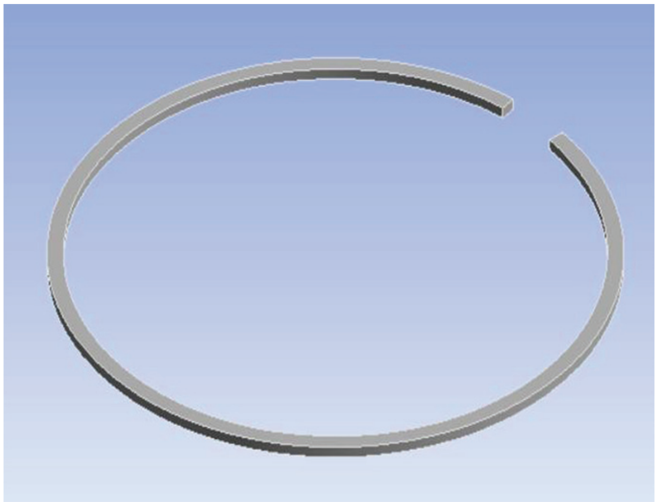

Figure 1: 3-D CAD Model of Piston ring

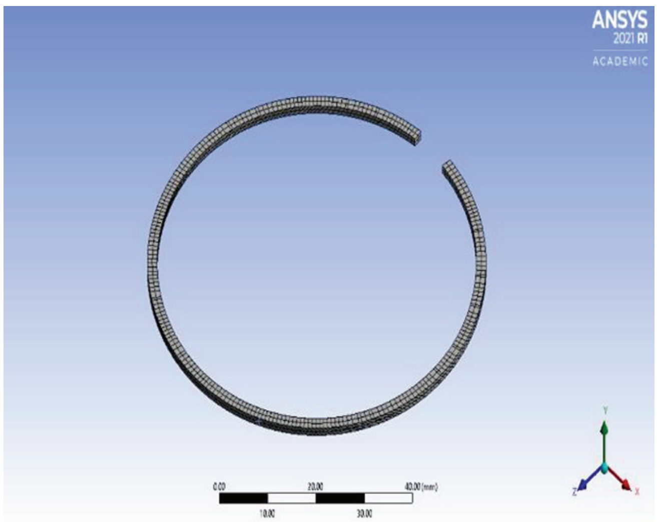

Figure 2: Mesh for SiC reinforced ZrB2 piston ring

2.5 Boundry conditions and loading for piston ring

After Meshing of piston ring, it is required to apply boundary condition under which the structural analysis will be performed. In static structural analysis, boundary conditions like supports and pressure is applied. Fixed supports are applied at piston ring outer surface and at the top of the pressure of 13.65 MPa is applied.

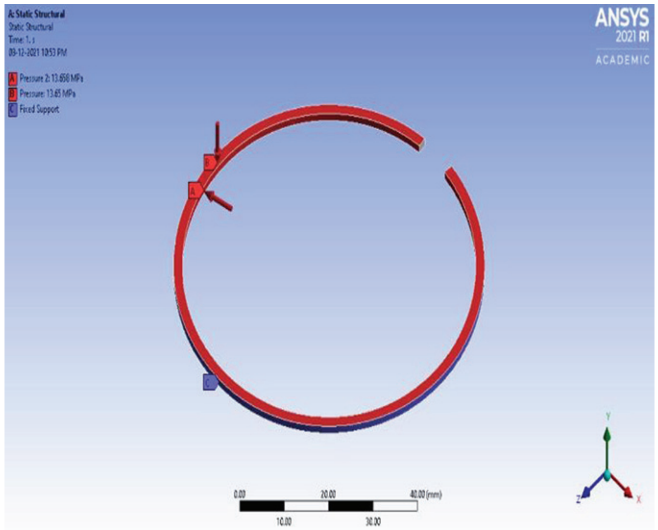

Figure 3: Boundary Condition

3.0 Results and discussion

3.1 Total Deformation

The Figures 4 to 6 present the piston ring deformations against SiC reinforced ZrB2, A360 and A2618. We can note total deformations occurred and were found at the bottom land of the piston ring for different materials. It is noted that SiC reinforced ZrB2 deforms less compared to A360 and A2618 material, and the highest deformation is 0.002989 mm for A360.

3.2 Strain

This Figures 7 to 9 reflects the equivalent strain on the SiC reinforced ZrB2, A360 and A2618 model and it is found that strain is maximum in A360 material and the minimum strain lies in the case of SiC reinforced

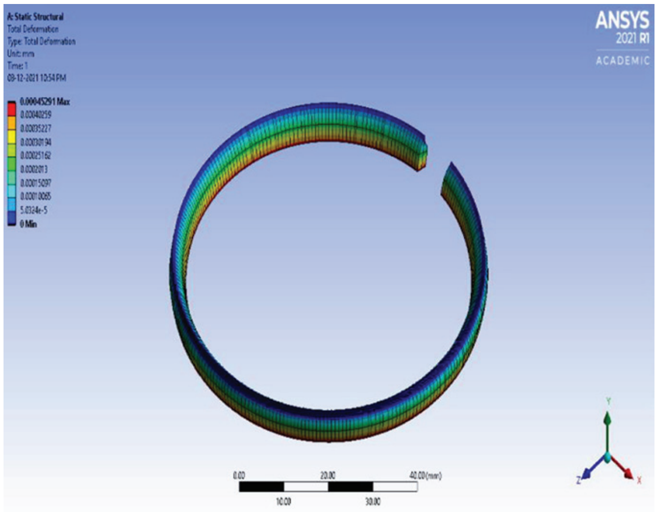

Figure 4: Total deformation with SiC reinforced ZrB2

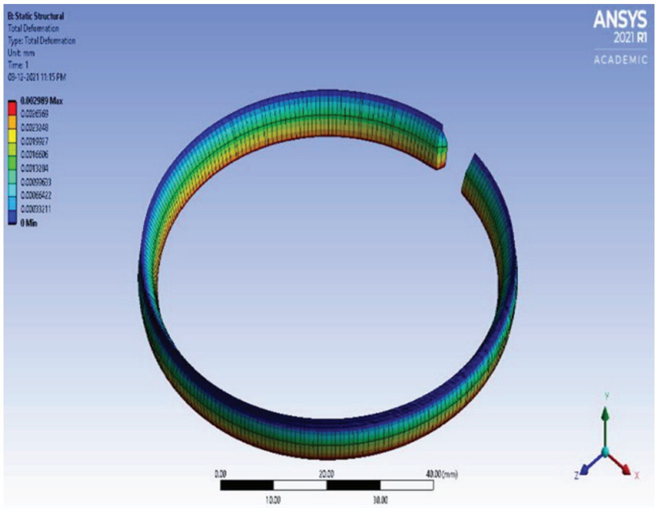

Figure 5: Total deformation with A360

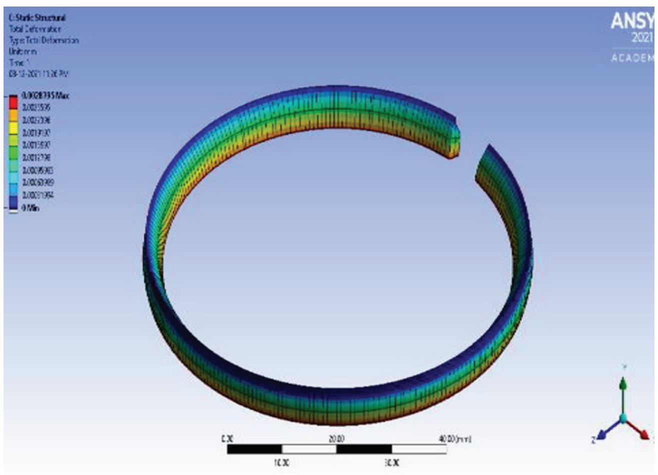

Figure 6: Total deformation with A2618

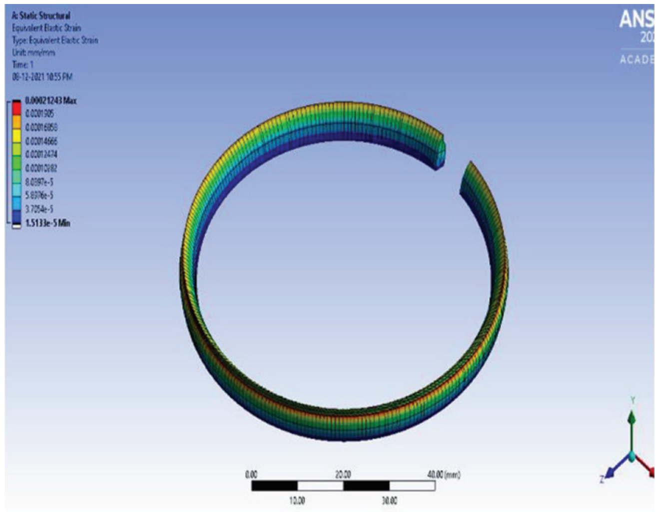

Figure 7: Strain in SiC reinforced ZrB2

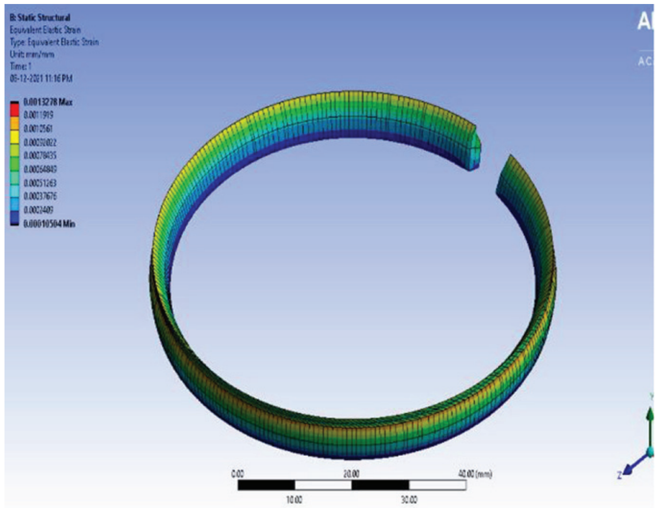

Figure 8: Strain in A360

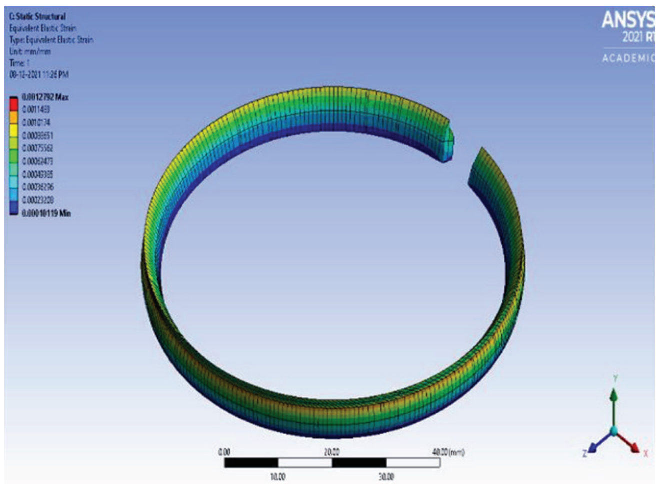

Figure 9: Strain in A2618

ZrB2. The measurement of maximum strain is 0.0013278 mm/mm in A360, and the minimum strain is 0.00021243 mm/mm in SiC reinforced ZrB2.

Table 3: Static structural analysis results for three materials

Piston ring material	Total deformation (mm)	Strain (mm/mm)
SiC reinforced ZrB2	0.00045291	0.00021243
A360	0.002989	0.0013278
A2618	0.0028795	0.0012792

4.0 Conclusion

Based on the above investigation, the analysis of the design of piston ring is done in solid works and static analysis on Ansys software 2021 R1 has been used. The design file is converted into IGS format and imported into Ansys for static analysis. The pressure is applied on the piston ring in the Ansys workbench – this test gives the result of total deformation and strain as tabulated and compared graphically. The main objectives of this project was to understand the response of the composite material when the specific pressure is applied. Comparing the results of the analysis of piston ring for three different materials, it was observed that the piston ring material of SiC reinforced ZrB2 is the best in terms of lowest stress on the piston ring and had comparatively less deformation. For piston rings, the best material is zirconium diboride with 20% SiC has least deformation, with lowest stress intensity. Further studies may be conducted with other engine components made using these materials to improve their strength and also to reduce their weight. In this way fuel consumption will be significantly reduced and the overall efficiency of the engine increases. From the result, it is concluded that this composite material SiC reinforced ZrB2 has less deflection whereas the piston ring made by Aluminium Alloy 2618 and Aluminium Alloy 360 has more deflection when the specific pressure is applied. A more uniform equivalent stress distribution is observed for both the materials of the piston ring yet SiC reinforced ZrB2 has a minimum generation advantage compared to A360 and A2618. The total deformation of the piston ring model increases in a noticeable way in stress analysis. Further, it has been observed from the model analysis that the stress for all the materials is within the allowable limits of the respective material. The piston ring is having more geometric stiffness so here we concluded that this composite material of SiC reinforced ZrB2 is the best choice to manufacture piston ring.

5.0 References

[1] Kiran S, Palanivendhan M, Kumar M. Modeling and Analysis of Pistons and Piston Rings of SI Engines for Various Materials Using FEM. In IOP Conference Series: Materials Science and Engineering 2020, (Vol. 993, pp. 012155-1—012155-16).

[2] Koszalka G, Suchecki A. Analysis of design parameters of pistons and piston rings of a combustion engine. In MATEC Web of Conferences (2017), (Vol. 118, pp. 00013-1—00013-5).

[3] Kurbet SN, Kumar RK. Mechanics and Stress Analysis of Piston Ring in Multibody Single Cylinder Internal Combustion Engine-Fe Analysis. SAE Technical Paper; (2001), (Vol. 2, pp. 368).

[4] Jayanth P, Sangeeth Kumar E. Investigation and Analysis of Wear Reduction in Piston Rings through Coating. In Applied Mechanics and Materials (2015), (Vol. 813 pp. 874-879).

[5] Krishnan BR, Ramesh M. Experimental evaluation of Al-Zn-Al2O3 composite on piston analysis by CAE tools. Mechanics and Mechanical Engineering. (2019), (Vol 1 pp. 212-217).

[6] Satyanarayana I, Renuka D. Design and analysis of piston and piston rings with cast iron, aluminium alloy and cast steel materials. IJISET—*Int J Innov Sci Eng*. Technol. (2016), (Vol. 3, pp. 104-111).

[7] Rajam CV, Murthy PV, Krishna MM. Non-linear static structural analysis of optimized piston for bio-fuel using Ansys. *International Journal of Management, IT and Engineering*. (2014), (Vol. 4, pp. 148-168).

[8] Srinadh M, Rajasekhara KB. Static and thermal analysis of piston and piston rings. *International Journal of Engineering Technology, Management and Applied Sciences*. (2015), (Vol. 3, pp. 51-58).

[9] Gopi E, Saleem M, Chandan S, Nema A. Thermal and static analysis of engine piston rings. *International Journal of Ambient Energy*. (2019), (pp. 1-5).

[10] Mereuta V. Static and Thermal Analysis of Piston using FEM Analysis. *International Journal for Research in Applied Science & Engineering Technology.*

(2018), (Vol. 6, pp. 2321-9653).

[11] Anugu AR, Reddy NV, Venkateswarlu D. Theoretical modelling and finite element analysis of automobile piston. Materials Today: Proceedings. (2021), (Vol. 45, pp. 1799-1803).

[12] Kumar KS. Design and analysis of IC engine piston and piston-ring on composite material using CREO and ANSYS software. *Journal of Engineering and Science.* (2016), (Vol. 01, pp. 39-51).

[13] Singh U, Lingwal J, Rathore A, Sharma S, Kaushik V. Comparative analysis of different materials for piston and justification by simulation. Materials Today: Proceedings. (2020), (Vol. 25, pp. 925-930).

[14] Darwai M, Kulshrestha A. A Review Paper on Steady State Thermal Analysis of Piston Using Composite Material. *International Journal of Scientific Research in Science and Technology.* (2017), (Vol. 3, pp. 635-642).

[15] Jain S, Khare N, and Sahu D. Analysis of engine piston and piston ring using CATIA and ANSYS for attaining higher Efficiency. (2015), (Vol. 4, pp. 29-35).

[16] Jog S, Anthony K, Bhoinkar M, Kadam K, Patil MM. Modelling and analysis of IC engine piston with composite material (AlSi17Cu5MgNi). In International Conference on Reliability, Risk Maintenance and Engineering Management (2019), (pp. 159-169).

[17] Rama PV, Krishna MP. Design and Analysis of IC Engine Piston with Different Materials. (2018), (Vol. 05, pp. 871-878).

[18] Lu X, Li Q, Zhang W, Guo Y, He T, Zou D. Thermal analysis on piston of marine diesel engine. *Applied Thermal Engineering.* (2013), (Vol. 50(1), pp. 168-176).

[19] Bhagat AR, Jibhakate YM. Thermal Analysis and Optimization of IC Engine Piston using finite element method. *Gas.* (2012), (Vol. 2(1), pp. 676-680).

[20] Singh AR, Sharma PK. Design, analysis and optimization of three aluminium piston alloys using FEA. *PARAMETERS.* (2014), (Vol. 4, pp. 94-102).

[21] Sonar DK, Chattopadhyay M. Theoretical analysis of stress and design of piston head using CATIA & ANSYS. *International Journal of Engineering Science Invention*. (2015), (Vol. 4, pp. 52-61).

[22] Santhosh MG. Static Structural, Fatigue and Thermal Analysis of marine Engine Piston and Piston ring Comparing with three different Materials. (2020), (Vol. 9, pp. 471-482).

[23] Moosavian H, Emamy M, Arani MM, Mahboubi S. The Study of Microstructures and Tensile Properties of an In Situ A356-ZrB2 Metal Matrix Composite. *In Key Engineering Materials* (2013), (Vol. 553, pp. 29-33).

[24] Ramesh CS, Pramod S, Keshavamurthy R. A study on microstructure and mechanical properties of Al 6061–TiB2 in-situ composites. *Materials Science and Engineering:* A. (2011), (Vol. 528, pp. 4125-4132).

[25] Dinaharan I, Murugan N. Microstructure and some properties of aluminium alloy AA6061 reinforced in situ formed zirconium diboride particulate stir cast composite. *International Journal of Cast Metals Research.* (2014), (Vol. 27, pp. 115-121).

[26] Andoko, Puspitasari P. Finite element analysis of surface tension on piston due to pressure variation. In AIP Conference Proceedings (2016), (Vol. 1778, pp. 030064-1—030064-7).

[27] Chougule SS, Khatawate VH. Piston strength analysis using FEM. *International Journal of Engineering Research and Applications* (IJERA). (2013), (Vol. 3, pp. 1724-1731).

[28] Munyao EM, He JG, Zhiyuan Y, Yi ZX. Simulation of Thermal-Mechanical Strength for Marine Engine Piston Using FEA. *Journal of Engineering Research and Applications.* (2014), (Vol. 4, pp. 319-323).

[29] Sharma S, Dhakar PS. A Review Study of Steady State Thermal Analysis of Piston by Finite Element Method (FEM). *International Journal of IC Engines and Gas Turbines*. (2018), (Vol. 3, pp. 34-39).

[30] John A, Mathew JT, Malhotra V, Dixit N. Design and analysis of piston by Sic composite material. *International Journal for Innovative Research in Science & Technology.* (2015), (Vol. 1, pp. 578-590).