Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 47 No. 02 (2026)

Transient Thermal Analysis of CAD configured IC Engine Piston to Understand it’s Thermal Behavior

Anjali Bal[1], Santosh R. Shekokar[2], Nitin A. Kharche[3], Yugesh A. Kharche[4]

[1]*P.G. student, Department of Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Maharashtra, India*

[2,3,4]*Department of Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Maharashtra, India*

Abstract

Modern IC engine pistons are highly precise and work under heavy thermal pressure. They are designed to withstand under thermal stress circumstances. Metallurgy behind the piston manufacturing allows him to control his workability in engine running conditions. It is one of the engine components which always work under different stresses and forces while engine runs. Friction and higher working temperature always challenge piston to work smoothly without failing. Most of the pistons are made up of aluminium alloys and has very smooth surface to reduce friction and they are oil cooled. As it works under higher temperature, it may affect the workability of piston and thermal stresses could cause the issues like crack propagation, wear and tear etc. It is observed that, piston experiences lots of forc-es which are transient or continuous in the nature as per the vehicle running requirements. Hence it is obvious to understand the behav-iour of piston during such loading conditions. There are several methods available to check the stress and deformation of the piston. Out of them Finite Element Analysis (FEA) is one of the advanced and most popular method to predict the regions of stress and defor-mation concentration caused due to thermos mechanical stresses. This method is also capable to find the effect and behaviour of pis-ton by thermal loading, pressure applied by the hot flue gases and the friction. In this project Transient thermal analysis by FEA package (ANSYS) is used to find the piston behaviour under various loading conditions. CAD model of piston is prepared by using CATIA software Configuration technique is used for modelling of piston. Then imported to .iges file format to perform thermal analysis under thermos mechanical loading conditions. Results obtained are described to understand the behaviour of the piston which allows to predict the possible failure regions.

Keywords: Transient Thermal Analysis, CAD Software, FEA package, CAD configuration

INTRODUCTION

An engine piston is a critical cylindrical component that converts the energy from fuel combustion into mechanical motion, enabling crankshaft rotation and engine operation. It performs essential functions such as force transmission, sealing, and heat transfer while operating under extreme mechanical and thermal conditions, including high pressures and temperatures. Pistons are typically made from aluminium alloys due to their lightweight nature, high thermal conductivity, and excellent strength under thermal stress. Modern piston design focuses on improving durability, reducing friction, minimizing emissions, and enhancing overall engine efficiency, making it a key element in high-performance engines.

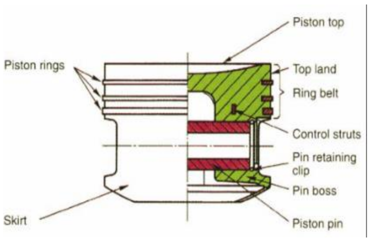


Fig 1 :- Important piston terms

LITERATURE REVIEW

Previous research on engine pistons mainly focuses on improving thermal performance, stress distribution, and material optimization under severe operating conditions. Studies highlight the use of thermal barrier coatings (TBC) and design optimization techniques to reduce temperature and thermal stress, thereby enhancing piston durability and engine efficiency. Finite Element Analysis (FEA) tools such as ANSYS, SolidWorks, and Fusion 360 are widely used to analyze stress, deformation, heat transfer, and temperature distribution under real engine conditions.

Several researchers have investigated the effects of different piston materials, including aluminium alloys, cast iron, and advanced composites, concluding that material selection significantly influences thermal resistance, deformation, and overall performance. Aluminium alloys remain the most preferred due to their lightweight and good thermal properties, although advanced materials show potential for improved performance.

Additionally, studies emphasize the impact of high combustion pressures, temperature gradients, and cyclic loading on piston failure, particularly in the crown region. Optimization of piston geometry, cooling mechanisms, and coating thickness plays a crucial role in reducing thermal stresses and preventing damage such as cracking or deformation.

Overall, the literature indicates that improving piston design through material selection, thermal analysis, and structural optimization is essential for achieving better engine performance, durability, and reduced emissions.

PISTON CAD MODEL

CATIA V5, developed by Dassault Systèmes, is a CAD/CAM/CAE tool used for 3D modelling and product development. The Sketcher mod-ule creates constrained 2D profiles, which are converted into 3D models in Part Design using operations such as Pad, Pocket, Shaft, and Rib.

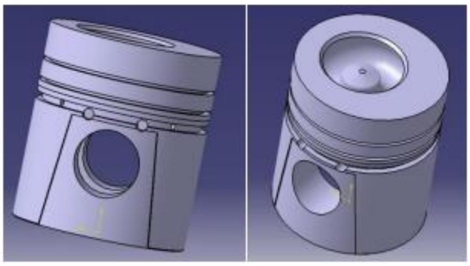


Fig 2 :- Piston cad model

Reverse Engineering Process

Reverse engineering is the process of reconstructing a 3D CAD model from an existing physical component without original design data. It involves capturing geometric information using techniques such as 3D scanning or CMM, followed by model reconstruction in CAD software. This approach is widely used when original drawings are unavailable, for product redesign, analysis, or replication.

The process typically includes three main steps: data acquisition (scanning the part), model refinement (converting scan data into an accurate CAD model), and manufacturing (producing or modifying the component). Reverse engineering enhances design recovery, im-proves product performance, and supports maintenance across industries.

FINITE ELEMENT METHOD

The engine piston model was developed using CATIA V5 with CAD configuration, enabling multiple design variations through parameter modification, and converted into STEP (ISO 10303) format for interoperability. Reverse engineering was applied to reconstruct CAD mod-els from physical components using scanning and model refinement techniques. The Finite Element Method (FEM) was then used to analyze the model by discretizing the domain into finite elements, enabling efficient structural and thermal analysis.

THERMAL ANALYSIS OF PISTON

ANSYS Tool

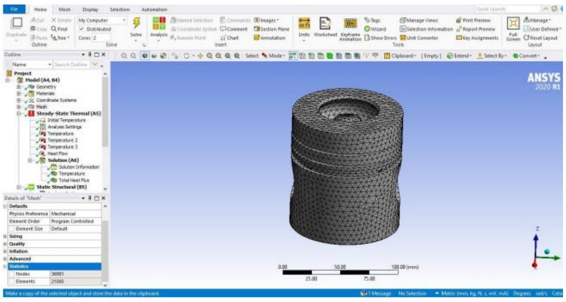
ANSYS is a finite element analysis (FEA) software used to simulate and analyze engineering problems such as temperature distribution, stress, and fluid flow. It helps predict product performance under different conditions without physical testing. Using ANSYS Work-bench, complex models are analyzed efficiently by dividing them into smaller elements.

Descretisation/Meshing of Piston.

Discretization is the process of converting a continuous physical model into a finite analytical model suitable for numerical analysis. In thermal analysis, this is achieved by dividing the geometry into smaller elements.

Two types of models are commonly used:

- Node-element model: Structural elements are represented by nodes connected through lines, where each node has degrees of freedom to simulate physical behavior.
- Finite element model (FEM): The domain is divided into a mesh of elements, allowing accurate prediction of stress, tempera-ture, and deformation.



Details of "Mesh"

Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	Default
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	36981
Elements	21046

Make a copy of the selected object and store the data in the clipboard.

Fig 3 :- : Meshing of Piston along with nodes and ele-ments

A mesh consists of interconnected nodes and elements that represent the geometry of the system. Proper meshing improves the accu-racy of simulation results.

In this study, the piston model is discretized using 3D tetrahedral elements in ANSYS to perform thermal analysis effectively.

Boundary Conditions

- The accuracy of thermal analysis largely depends on the proper application of boundary conditions. In this study, realistic thermal conditions were applied to simulate the actual working environment of the piston.
- The temperature distribution across the piston was defined based on engine operating conditions. A maximum temperature of 1200°C was applied at the combustion chamber surface, while 1100°C was assigned to the piston crown region. The lower por-tion of the piston was maintained at a minimum temperature of 100°C, representing cooling effects.
- These conditions help in accurately capturing the thermal gradients within the piston body.
- The material properties assigned for the analysis include:
- Young’s Modulus: 143 GPa
- Density: 8249 kg/m³
- Thermal Conductivity: 20 W/m·K
- Poisson’s Ratio: 0.344

- All boundary conditions were implemented using ANSYS Workbench to ensure realistic simulation of thermal behavior.

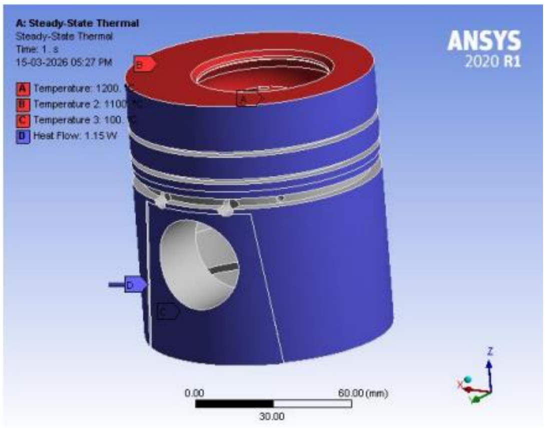


Fig 4 :- Boundary Condition (Min. and Max. Temperature) on Piston

Steady-State Thermal Analysis

- Steady-state thermal analysis was performed to evaluate the temperature distribution and heat transfer characteristics of the piston under constant thermal loading conditions. This analysis assumes that temperature remains constant with time and helps identify critical regions subjected to maximum thermal stress.
- The simulation results indicate that the maximum temperature observed on the piston is approximately 1202.8°C, primarily concentrated at the piston crown and combustion chamber region. This high-temperature zone extends slightly towards the piston ring area, indicating significant thermal exposure in these regions.
- The heat flux distribution shows that the maximum heat flux occurs at the top surface and near the edges of the combustion chamber, with a value of approximately 24.6 W/mm². These regions are subjected to intense heat transfer due to direct exposure to combustion gases.
- The analysis reveals that the piston crown is the most critical region in terms of thermal loading and is more prone to thermal stress and potential failure. However, due to sufficient material thickness and support in this region, the structural integrity of the piston remains stable.
- Overall, steady-state analysis provides an initial understanding of thermal behavior and helps identify high-temperature zones, which are crucial for design improvement and material selection.

Fig.5: Temperature Contour on Piston Profile

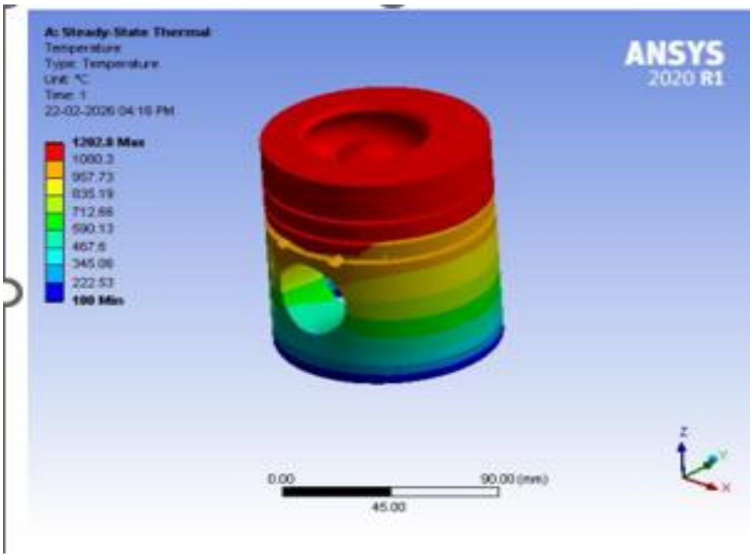
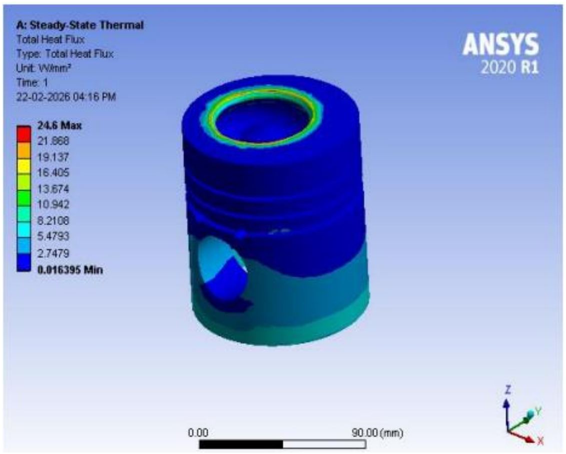


Fig. 6 . Total Heat Flux along the blade profile.



Transient Thermal Analysis

Transient state thermal analysis is performed to find the behavior of piston under dynamic condition. In this case piston is con-sidered in dynamic condition for 15 second. Hence the load applied on the piston and the temperature will be for 15 seconds. Due to this dynamic condition, results obtained are studied and explained as follows

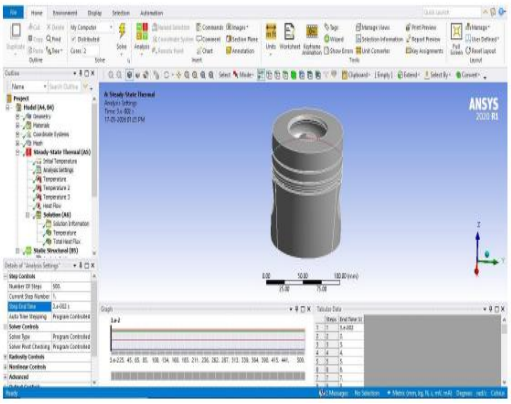


Fig 7 Transient state cycle applied for 15 second

Figure 7 shows the Transient state cycle applied for 15 second. It generates the iterations for considering 15 seconds run condi-tion. During these iterations both structural and thermal loading is considered.

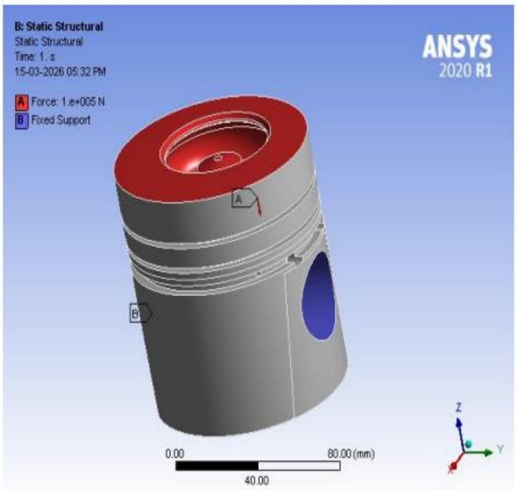


FIG 8 Structural Boundary conditions applied on Piston.

Figure 8 shows the Structural Boundary conditions applied on Piston. It is considered that the maximum of 100 KN force can be applied on the piston during power stroke. Fixed boundary conditions are applied on the king pin section where piston connects with connecting rod. Force is applied vertically downward to simulate power stroke.

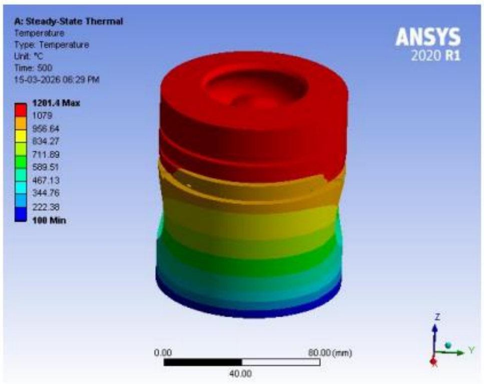


Fig 9 :- Temperature contours generated with Transient thermal analysis

If we consider temperature contours shown in figure 9 with steady state thermal analysis contours, we can find that the tem-perature increases on the piston ring section. This happens due to the dynamic conditions for 15 seconds

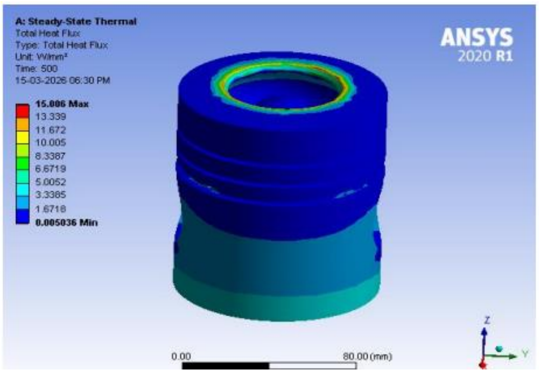


Fig 10 - Total Heat Flux along the Piston profile

Figure 10 shows the total heat flux along the Piston profile. The value of total heat flux obtained in this case is 15 W/mm2 which less than the steady state thermal analysis. The heat flux reduces due to the dynamic conditions of the piston. It shows the major changes in dynamic behaviour.

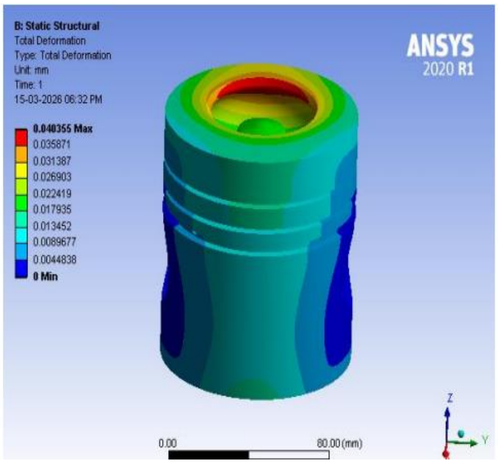


Fig 11 :- Deformation due to Structural and Thermal Loading

As we considered dynamic condition, we also need to find the deformation due to the thermal loading. In this case we also have structural loading which is mainly due to the power stroke on piston head. Figure 11 shows the deformation due to both struc-tural and thermal loading. This deformation is not more than 0.5 mm hence deviation of piston is under control.

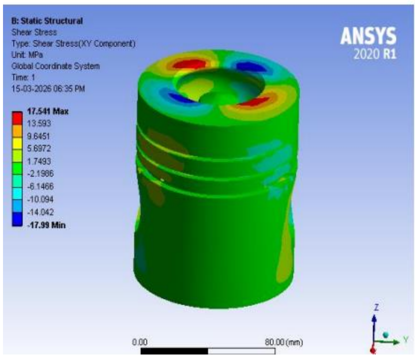


Fig 12 :- Shear Stress due to Structural and Thermal Loading

Figure 12 shows the shear stress due to structural and thermal loading. The shear stress found with much controlled value and the piston can with stand on this condition for a long period of time with several time intervals

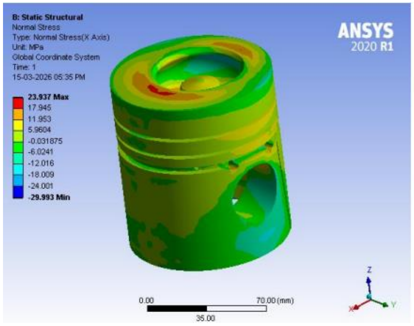


Fig 13 :- Normal Stress due to Structural and Thermal Loading

Figure 13 shows the normal stress obtained due to the thermal and structural loading. Normal stresses are found up to 25 MPa which is considerable and shows stable behaviour.

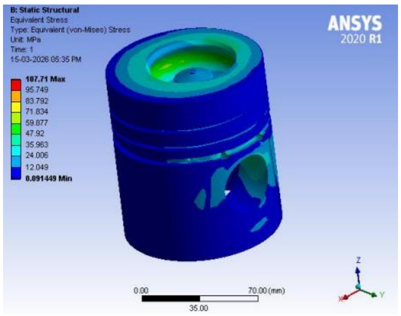


Fig 14 :- Equivalent Stress due to Structural and Thermal Loading

Result Observation

If we summaries all the results generated through the steady state thermal analysis and the transient state, it is observed that the both are having different boundary conditions and states of consideration. Hence the results generated will have significant differences with each other. The entire analysis result systhesis is given next below

RESULT SUMMERY

The detailed summery of the results obtained from both steady state and transient state thermal analysis can be tabulated in following table.

Sr. No.	Analysis Type	Result	Value

1	Steady State Thermal Analysis	Temperature Contours	1202.8 °C
		Heat Flux	15 W/mm²
2	Static Structural Analysis	Total Deformation	0.046 mm
		Shear Stress	17.5 MPa
		Normal Stress	23.68 MPa
		Equivalent Stress	106.79 MPa
3	Transient State Thermal Analysis	Temperature Contours	1201.4 °C
		Heat Flux	25 W/mm²
		Total Deformation	0.040 mm
		Shear Stress	17.54 MPa
		Normal Stress	23.93 MPa
		Equivalent Stress	107.71 MPa

The detailed observations from the above results are as follows

1) Temperature Contours: Temperature observed in transient state thermal analysis is less than the steady state thermal analysis. It is mainly due to the heat flows through the piston wall. In transient state heat flows for 15 seconds more than the steady state. Hence the results obtained are accurate.

2) Heat flux: Apposite as the temperature contours heat flux is more in transient state compared with the steady state due to the heat flow. Heat transfer per unit volume is the heat flux and it will be more in dynamic state of piston

3) Total Deformation: As we see the deformation in both static structural and transient state analysis found approximately same. This deformation will not affect the working of piston

4)) Shear Stress: Shear stress is also same in both structural and transient state thermal analysis. This is due to the same loading condition in both cases which has similar thermal effect

5) Normal Stress: Normal stress in both cases is observed same.

6) Equivalent Stress: Same stresses observed in both structural and transient state thermal analysis.

Note: If we consider deformation and all stresses results for both structural and transient state thermal analysis, it is ob-served same. But there is slight difference between them. This difference will be gotten increased if we increase time duration for transient state analysis. But due to the system limitation it could be increased for greater value (5 Minutes and more). Higher end computer workstations can carry such large processing calculation and can obtain results for greater time period.

CONCLUSION

By observing all the results generated through all types of analysis, we can conclude that, the transient state thermal analysis is the best way to study behavior of Piston in dynamic condition as we can simulate exact running condition of the piston. Also, the behavior of the piston found stable in dynamic condition. Hence no need of design update can be considered. Region where the maximum temperature accurse on the piston top can be coated to enhance the life of the piston. The durability and the life of the piston totally depend on the generated heat on the combustion chamber. Hence the prevention of coating can in-crease the life of the piston

REFERENCES

[1] Yang Liu a,b , Jilin Lei a,b,* , Xiwen Deng a,b , Yi Liu a,b , Dongjun Sun c , Yuankan Zhang c, “Research and analysis of a thermal optimisation design method for aluminium alloy pistons in diesel engines”. Contents lists available at ScienceDirect Case Studies in Thermal Engineering, Available online 24 October 2023 2214-157X/© 2023 The Authors. Published by Elsevier Ltd.

[2] D.Hari krishna1 , CH.Veeru Naidu2 , A.Narendhra Kumar3, “Thermal Analysis of Different Piston Head Profiles by Using FEM”. International Journal for Multidisciplinary Research (IJFMR) E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: edi-tor@ijfmr.com, IJFMR230611430 Volume 5, Issue 6, NovemberDecember 2023

[3] Ambarev, K.; Taneva, S. “Thermal and Structural Analysis of Gasoline Engine Piston at Different Boost Pressures”. Eng. Proc. 2025, 100, 38. https://doi.org/10.3390/ engproc2025100003

[4] Mr. Ratnakar Lande, 2Prof. Prashant Awachat, 3Prof. Tejpal Parshiwanikar, “ANALYSIS AND OPTIMIZATION OF PISTON OF IC ENGINE”. www.ijcrt.org © 2021 IJCRT | Volume 9, Issue 7 July 2021 | ISSN: 2320-2882, IJCRT2107343 International Journal of Crea-tive Research Thoughts (IJCRT) www.ijcrt.org d92

[5] Neha Choubeya,∗ , Ashish Kumar Shrivastavab , Abhishek Choubeyb , Swapnil Singhc , Balendra Bhaskard, “Thermal analy-sis on two wheeler piston with different materials by using FEA method”. Int. J. Nonlinear Anal. Appl. 13 (Special issue for ICDACT-2021), 147–155 ISSN: 2008-6822 (electronic) http://dx.doi.org/10.22075/ijnaa.2022.6340

[6] Ravi Ranjan1 , Prof. D. S. Rawat2 and Dr. Sumit Rai2, “Thermal Analysis of Piston, Connecting Rod and Crank Shaft Assembly using Catia and Ansys Software; A Review”. International Journal of Research Publication and Reviews, Vol 5, no 1, pp 594-598 January 2024.

[7] Mr. N. Raghuveer1 , Puli Hari Shankar2 , Kadiyala Rupananda Ganesh Kumar3 , Ramavath Arun Kumar Naik4 , Sai Durga Nishith Medisetti5, “Design and Simulation of Steady State Thermal Analysis of Exhaust Engine Valve”. International Journal of Scientific Research & Engineering Trends Volume 11, Issue 2, Mar-Apr-2025, ISSN (Online): 2395-566X

[8] Vijay Pokharkar1, Saurbh Palkhe2, Aditya Pawar3, Aaditya Yadav4, “Thermal Antlysis of Piston”. International Research Jour-nal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 08 Issue: 05 | May 2021 www.irjet.net p-ISSN: 2395-0072

[9] Subodh Kumar Sharma,1 P. K. Saini,2 and N. K. Samria3, “Experimental Thermal Analysis of Diesel Engine Piston and Cylinder Wall”. Hindawi Publishing Corporation Journal of Engineering Volume 2015, Article ID 178652, 10 pages http://dx.doi.org/10.1155/2015/178652

[10] Chandra Mohana Reddy G1 , Safeeruddin Khan2 , Abdul Saddique Shaik3 , and Murali Krishna CH1, “Performing FEM Anal-ysis to Evaluate the Static and Thermal Characteristics of a Piston”. MATEC Web of Conferences 405, 03007 (2024) ICASMMT 2024 https://doi.org/10.1051/matecconf/20244050300