iJRASET

International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IX **Month of publication:** September 2025

DOI: https://doi.org/10.22214/ijraset.2025.74273

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

Design and Analysis of a Spark-Ignition (SI) Engine Piston Made of Aluminum Alloy 7475-T761

Y. Rameswara Reddy
Assistant Professor, Dept of Mechanical, JNTUACE, Pulivendula, AP, India,

Abstract: A piston is a critical component used in reciprocating engines, pumps, gas compressors, and pneumatic cylinders. It is the moving part contained within a cylinder, sealed gas-tight using piston rings. The primary function of the piston is to convert the energy from expanding gases into mechanical work. It moves within the cylinder liner or sleeve, typically made from high-strength materials to withstand combustion forces and wear. Pistons are commonly manufactured using aluminum alloys or cast iron due to their favorable strength-to-weight ratios and thermal properties. The main aim of this project is to design and analyze a piston for a two-wheeler engine, considering three different materials: Cast Iron, Aluminum Alloy 7475-T761, Aluminum Metal Matrix Composite (MMC). The piston designs are modeled using Pro/ENGINEER (PRO-E) 3D CAD software. Finite Element Analysis (FEA) and performance simulations are carried out using SolidWorks Simulation. n mechanical design, design evaluation is crucial for verifying performance, safety, and efficiency. In this project, the evaluation is performed through Design Optimization, using the following criteria: Constraints: Maximum allowable stress and deformation. Variables: Piston head thickness, Goal: Minimization of piston mass without compromising strength or functionality. By evaluating multiple design iterations under the defined constraints and objectives, the optimal piston design will be identified. This design will offer the best balance between strength, weight, and material performance, suitable for application in a two-wheeler engine.
Keywords: Two Wheeler Piston, PRO-E, Solid Works, Aluminum Alloy (7475-T761).

I. INTRODUCTION

In every engine, piston plays an important role in working and producing results. Piston forms a guide and bearing for the small lend of connecting rod and also transmits the force of explosion in the cylinder, to the crank shaft through connecting rod. The piston is the single, most active and very critical component of the automotive engine. The Piston is one of the most crucial, but very much behind-the-stage parts of the engine which does the critical work of passing on the energy derived from the combustion within the combustion chamber to the crankshaft. Simply said, it carries the force of explosion of the combustion process to the crankshaft. Apart from the critical job that it does above, there are certain other functions that a piston invariably does -- It forms a sort of a seal between the combustion chambers formed within the cylinders and the crankcase. The pistons do not let the high pressure mixture from the combustion chambers over to the crankcase.

A. *Construction of Piston*

Its top known by many names such as crown, head or ceiling and thicker than bottom portion. Bottom portion is known as skirt. There are grooves made to accommodate the compression rings and oil rings. The groove, made for oilring, is wider and deeper than the grooves made for compression ring. The oil ring scraps the excess oil which flows into the piston interior through the oil return holes and thus avoiding reaching the combustion chamber but helps to lubricate the gudgeon pin to some extent. In some designs the oil ring is provided below the gudgeon pin boss .The space between the grooves are called as lands. The diameter of piston always kept smaller than that of cylinder because the piston reaches a temperature higher than cylinder wall and expands during engine operation. The space between the cylinder wall and piston is known as piston clearance. The diameter of the piston at crown is slightly less than at the skirt due to variation in the operating temperatures. Again the skirt itself is also slightly tapered to allow for unequal expansion due to temperature difference as we move vertically along the skirt the working temperature is not uniform but slightly decrease. Cast Iron, Aluminum Alloy and Cast Steel etc. are the common materials used for piston of an Internal Combustion Engine. Cast Iron pistons are not suitable for high speed engines due its more weight. These pistons have greater strength and resistance to wear. The Aluminum Alloy Piston is lighter in weight and enables much lower running temperatures due to its higher thermal conductivity. The coefficient of expansion of this type of piston is about 20% less than that of pure aluminum piston but higher than that of castiron piston and cylinder wall. To avoid seizure because of higher expansion than cylinder wall, more piston clearance required to be provided. It results in piston slap after the engine is started but still warming up and tendsto separatethe crown from the skirt of the piston.

B. Parts inside the Piston

1) Piston Heador Crown: The piston head or crown maybe that convex or concave depending upon the design of combustion chamber.
   - It with stands the pressure of gas in the cylinder.
   - The selection of piston crown primarily depends upon the requirement of values for the combustion chamber.
2) Piston Rings: These are used to seal the cylinder in order to prevent heritage of the gas past the piston.
   - To act as passage of heat flow from piston crown to the wall of the cylinder.
   - To act as a lubricating oil controller on the cylinder wall so as to minimize wear.
   - To absorb some part of the piston due to sidethrust.
   - The material for piston rings is usually castiron& alloy cast iron due to their good wearing qualities & also they retain the spring characteristics ever at high temperatures.
   - Piston Rings Are Two Types:-
     1. Compression rings
        - Sealing of the combustion gas.
        - Heat transfer from piston crown to the cylinder wall.
   - Oil control rings ----- > to prevent excessive oil from Passing through the end gap of rings and between the cylinder wall & the ring face.

II. METALMATRIXCOMPOSITE

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermet.

A. Composition

MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix. For example, carbon fibers are commonly used in aluminum matrix to synthesize composites showing low density and high strength. However, carbon reacts with aluminum to generate a brittle and water-soluble compound Al_4C_3 on the surface of the fiber. To prevent this reaction, the carbon fibers are coated with nickel or titanium boride.

Matrix: The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common.

Reinforcement: There in for cement material is embedded into the matrix. There inforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. There in for cement can be either continuous, or discontinuous. Discontinuous MMCscan be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging orrolling. In addition, they may be machined using conventional techniques, but commonly would need the use of polycrystalline diamond tooling (PCD).

Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide.

III. MANUFACTURING AND FORMING METHODS

MMC manufacturing can be broken into three types: solid, liquid, and vapor.

A. Solid State Methods

1) Powder blending and consolidation (powder metallurgy): Powdered metal and discontinuous reinforcement are mixed and then bonded through a process of compaction, degassing, and thermo-mechanical treatment (possiblyvia hot isostatic pressing (HIP) or extrusion).
2) Foil diffusion bonding: Layers of metal foil are sandwiched with long fibers, and then pressed through to form a matrix.

B. Liquid State Methods

1) Electroplating / Electroforming: A solution containing metal ions loaded with reinforcing particles is co- deposited forming a composite material.
2) Stir casting: Discontinuous reinforcement is stirred into molten metal, which is allowed to solidify.
3) Squeeze casting: Molten metal is injected into a formwith fibers preplaced inside it.
4) Spray deposition: Molten metal is sprayed onto a continuous fiber substrate.
5) Reactive processing: A chemical reaction occurs, with one of the reactants forming the matrix and the other the reinforcement.

C. Vapor Deposition

Physical vapor deposition: The fiber is passed through a thick cloud of vaporized metal, coating it.

In Situ Fabrication Technique: Controlled unidirectional solidification of a eutectic alloy can result in a two-phase microstructure with one of the phases, present in lamellar or fiber form, distributed in the matrix.[2]

IV. INTRODUCTIONTOPRO/ENGINEER

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products. Customer requirements may change and time pressures may continue to mount, but your product design needs remain the same - regardless of your project's scope, you need the powerful, easy-to-use, affordable solution that Pro/ENGINEER provides.

A. Pro/ENGINEER Wildfire Benefits

1) Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability.
2) Fully integrated applications allow you to develop everything from concept to manufacturing within one application.
3) Automatic propagation of design changes to all downstream deliverables allows you to design with confidence
4) Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals.
5) Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency.

V. MODELOFPISTON

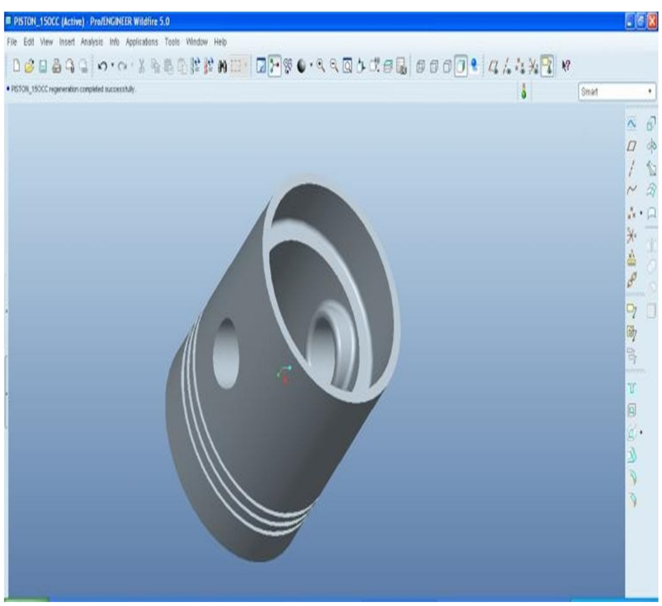


Fig.1.

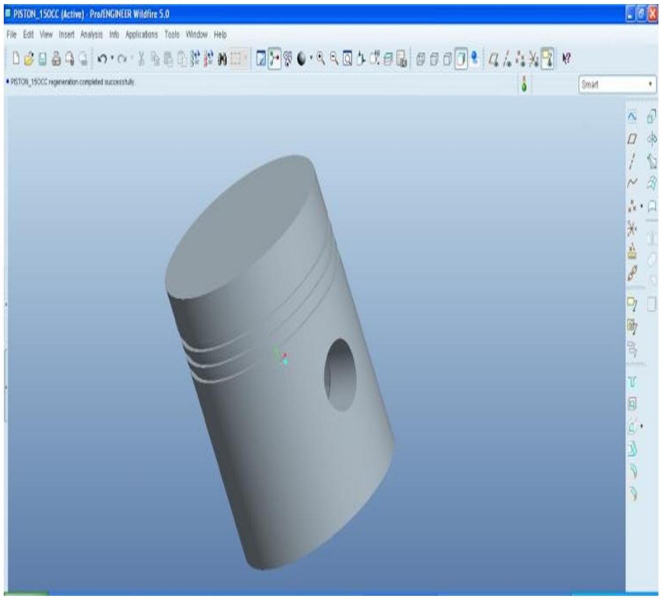


Fig.2.

VI. ANALYSISOFPISTON

A. Introduction to COSMOSWORKS

COSMOSWORKS is useful software for design analysis in mechanical engineering. That's an introduction for you who would like to learn more about COSMOSWORKS. COSMOS WORKS is a design analysis automation application fully integrated with Solid Works. This software uses the Finite Element Method (FEM) to simulate the working conditions of your designs and predict their behavior. FEM requires the solution of large systems of equations. Powered by fast solvers, COSMOSWORKS makes it possible for designers to quickly check the integrity of their designs and search for the optimum solution. A product development cycle typically includes the following steps:

- Build your model in the Solid Works CAD system.
- Prototype the design and Test the prototype in the field.
- Evaluate the results of the field tests.
- Modify the design based on the field test results.

1) Analysis Steps

You complete a study by performing the following steps:

- Create a study defining its analysis type and options.
- If needed, define parameters of your study. Parameters could be a model dimension, a material property, a force value, or any other entity that you want to investigate its impact on the design.

2) Analysis Background

Linear Static Analysis Frequency Analysis Linearized Buckling Analysis Thermal Analysis Optimization Studies, Material property, Material Models, Linear Elastic Isotropic.

- Plotting Results: Describes how to generate a result plot and result tools.
- Listing Results: Overview of the results that can be listed.
- Graphing Results: Shows you how to graph results.
- Results of Structural Studies: Lists results available from structural studies.
- Results of Thermal Studies: Lists results available from thermal studies.
- Reports: Explains the study report utility.
- Stress Check: Lists the basics of checking stress results and different criteria used in the checking.

B. CastIron Metal Matrix Composite

Study name	PISTON CI
Analysis type	Static

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.512339 N/mm^2 (MPa) Node: 15996	139.006 N/mm^2 (MPa) Node: 17698

Fig 5.2.5 (a) PISTON-PISTON CI-Stress-Stress1

Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SolidWorks document (C:\Documents\DESIGN\SW\piston)

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	6.72647e-006 Element: 4604	0.000995247 Element: 7946

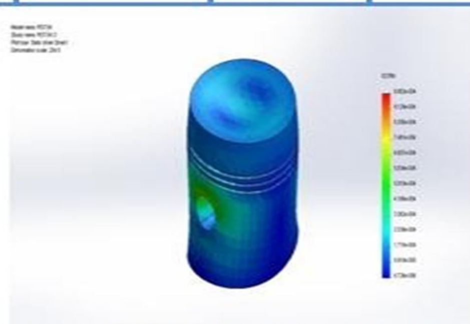


Fig 5.2.5(c) PISTON-PISTON CI-Strain-Strain1

C. *Aluminum Metal Matrix Composite*

Solid Bodies		
Document Name and Reference	Treated As	Volumetric Properties
Fillet3 	Solid Body	Mass:0.249261 kg Volume:8.65488e-005 m^3 Density:2880 kg/m^3 Weight:2.44275 N

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.06347 N/mm^2 (MPa) Node: 13915	180.598 N/mm^2 (MPa) Node: 16663

Name	Type	Min	Max

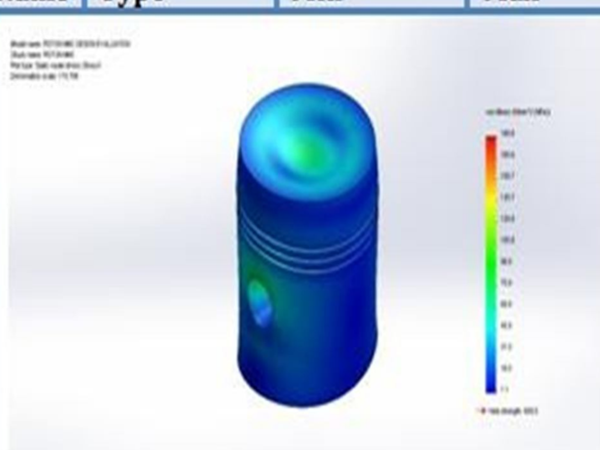


Fig 5.3.5 (a) PISTON MMC DESIGN EVALUATION-PISTON MMC-Stress-Stress1

Solid Bodies		
Document Name and Reference	Treated As	Volumetric Properties
Fillet3 	**Solid Body**	Mass:0.25000000 kg Volume:9.15989e-005 m^3 Density:2810 kg/m^3 Weight:2.52245 N

D. AluminumAlloy7475-T761 Study Properties

Study name	PISTON ALLOY
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SolidWorks Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off

1) Material Properties

Model Reference	Properties	
	Name: Model type: Default failure criterion: Yield strength: Tensile strength: Elastic modulus: Poisson's ratio: Mass density: Shear modulus: Thermal expansion coefficient:	7475-T761, Plate (SS) Linear Elastic Isotropic Max von Mises Stress 4.05e+008 N/m^2 5.7e+008 N/m^2 7.2e+010 N/m^2 0.33 2810 kg/m^3 2.79e+010 N/m^2 2.2e-005 /Kelvin

VII. STUDYRESULTS

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.02872e-005 Element: 3671	0.00126389 Element: 10894

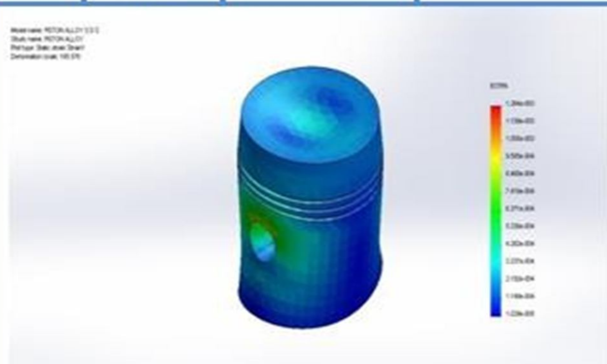


Fig 5.4.3 (c) PISTON ALLOY S D S-PISTON ALLOY-Strain-Strain1

A. Results

1) Aluminum Metal Matrix Composite

Study Properties:

Study name	Design Study 1
Analysis type	Design Study(Optimization)
Design Study Quality	High quality (slower)
Result folder	SolidWorks document(C:\DESIGN\SW\piston)

Study Results:

Component name	Current	Initial	Optima 1	Iteration 1	Iteration 2
MMC	8	12.0348 1	8	8	12
Stress1	180.6	129.77	180.6	180.6	128.6
Mass1	86.548 8	91.5989	86.548 8	86.5488	91.5553

Compognent name	Iteration3
MMC	10
Stress1	156.01
Mass1	89.0521

2) AluminumAlloy7475-T761

Study Properties:

Study name	Design Study 1
Analysis type	Design Study(Optimization)
Design Study Quality	High quality (slower)
Result folder	SolidWorks document(C:\DESIGN\SW\piston sw\COSMOS STATIC PISTON)

Study Results

Component name	Current	Initial	Optima 1	Iteration 1	Iteration 2
ALLOY	8	12.03	8	8	12
Stress1	178.09	126.43	178.09	178.09	125.01
Mass1	86.54	91.59	86.54	86.54	91.55

Compognent name	Units	Iteration3
ALLOY	mm	10
Stress1	N/mm^2 (MPa)	153.78
Mass1	g	89.0521

Name	Type	Min	Max
Stress1	VON: von Mises Stress	0.913657 N/mm^2 (MPa) Node: 6637	178.089 N/mm^2 (MPa) Node: 16663

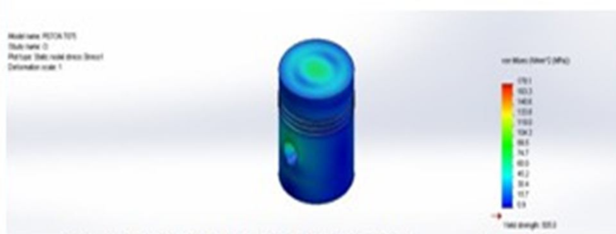


Fig 6.1.3 PISTON 7475-T761-CI-Stress-Stress1

Results Table

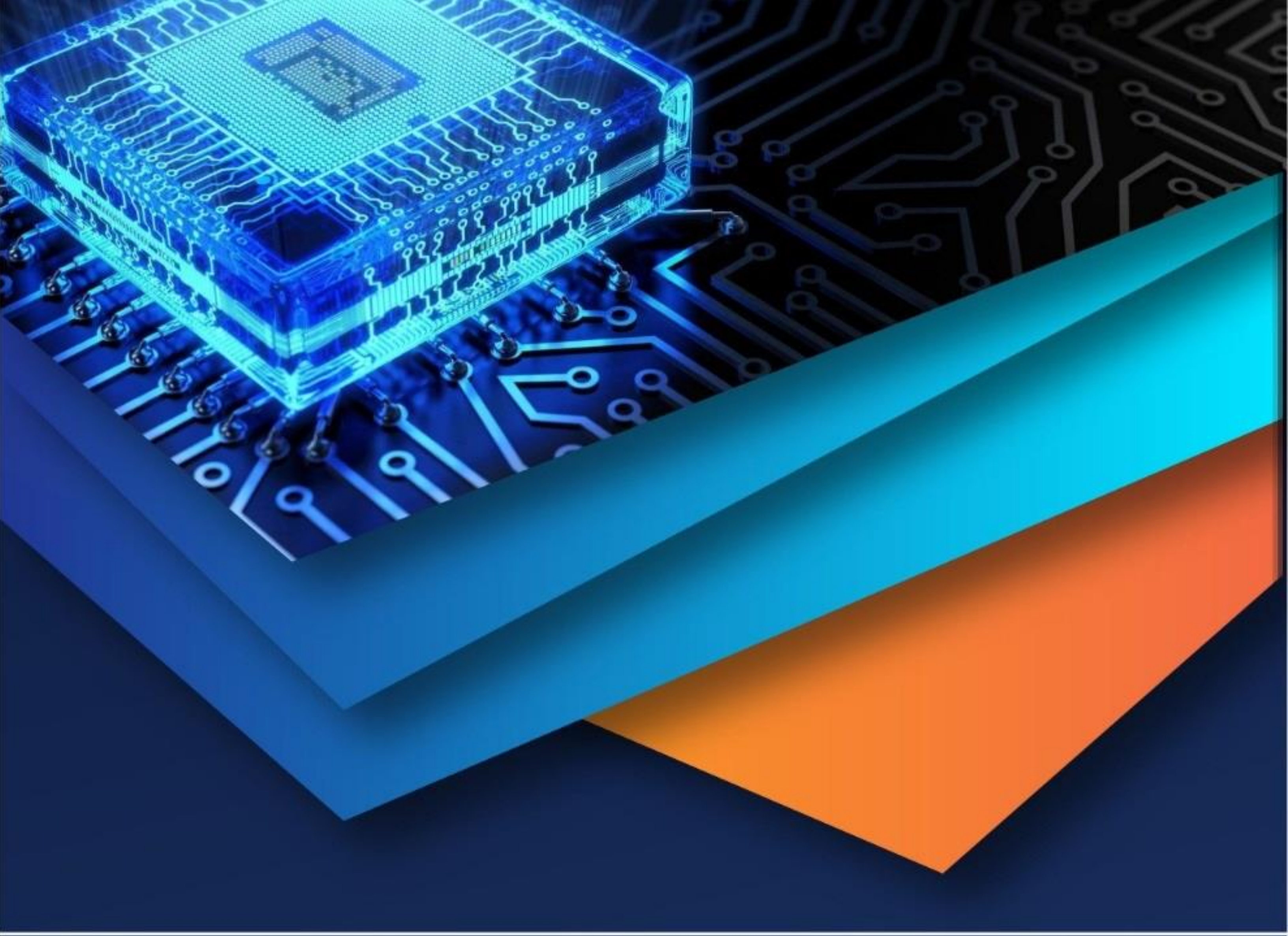
	CAST IRON	ALUMINUM MMC	ALUMINUM 7475
STRESS (MPa)	139.006	180.6	126.431
DISPLACEMENT (mm)	0.0339	0.039	0.042
STRAIN	0.00099	0.00096114	0.001263

VIII. CONCLUSION

In this paper a piston used in two wheeler is designed using theoretical calculationsand modeledin3D modeling software Pro/Engineer. The present used material for piston is CastIron and Aluminum alloy A360. In this project, we are replacing with Aluminum alloy 7475-T761 and Aluminum metal matrix composite. The advantage of aluminum alloys over cast iron is their less weight. The strength of Aluminum alloy 7475-T761 and Aluminum metal matrix composite is more than that of Aluminum alloy 7475-T761. Structural analysis is done on the piston for three materials Cast Iron, Aluminum alloy 7475-T761 and Aluminum metal matrix composite. By observing the analysis results, the stress values for both the materials Aluminum alloy 7475-T761 and Aluminum metal matrix composite are less than that of their respective yield stress values. The stress value is less for Aluminum alloy 7475-T761 compared with the other two materials. So using aluminum alloy 7475-T761 is better. The thickness of the piston from theoretical calculations is 12mm.

REFERENCES

[1] Srecko Manasijevic, Radomir Radisa, Srdjan Markovic, Zagorka Acimovic- Pavlovic KarloRaic,"Thermalanalys is and microscopic characterization of the pistonalloy AlSi13Cu4Ni2Mg",Intermetallics 19 (2011) 486 – 492.
[2] GudimetalP, GopinathC.V, "Finite Elementanalysis of Reverse Engineered Internal Combustion Engine Piston", AIJSTPME (2009) 2(4): 85-92.
[3] Esfahanian, A. Javaheri, M. Ghaffarpour, "Thermal analysis of an SI engine piston using different combustion boundary condition treatments", Applied Thermal Engineering 26 (2006) 277.
[4] C.H. Li., Piston thermal deformation and friction considerations, SAE Paper 820086, 1982.
[5] Y. Liu. and R.D. Reitz, Multidimensional modeling of combustion chamber surface temperatures, SAE Paper 971539, 1997.
[6] Handbook of Internal Combustion Engines, SAE International.
[7] Thermal Analysis Of A Piston Of Reciprocating. Air Compressor. Bhaumik Patel1, Ashwin Bhabhor .I/ Issue III/April-June, 2012/73- 75. Research Paper B. Heywood John, Internal Combustion Engine Fundamentals, McGraw- Hill, New York, 1988.
[8] D. V. Hutton, "Fundamentals of Finite Element Analysis", International Edition, McGraw Hill, 2004.
[9] Aluminium matrix composites: Challenges and opportunities. MKSURAPPA. Department of Metallurgy, Indian Institute of Science, Bangalore
[10] F.M. Hosking, F. Folgar-Portillo, R. Wunderlin and R. Mehrabian, Composites of aluminium alloys: Fabrication and wear behaviour, J.Mater. Sci., 17 (1982) 477498.
[11] S.V. Prasad and P.K. Rohatgi, Tribological properties of Al alloy particle composites, J. Met, 39 (1987) 22-2
[12] Xiaomin Ni, MS. Maclean and T.N. Baker, Designaspects of processing of aluminium 6061 based metal matrix composites viapowdermetallurgy,Mater.Sci.Tech&.,10 (1994) 452459.2010.



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY