



Comparative And Design Analysis Of Al6061 And Al4032 Materials For Enhanced Performance In Ic Engine Piston-150cc

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Abstract:

The piston is a key part of internal combustion (IC) engines, which is very important for determining engine performance, efficiency, and longevity. This research emphasizes the design and analysis of a four-stroke single-cylinder piston for the Bajaj Pulsar 150 engine based on various materials such as aluminum alloy, gray cast iron, and magnesium alloy. Structural and thermal analysis was performed by using CATIA for modelling and ANSYS for simulation to analyze total deformation, shear stress, temperature distribution, and heat flux. The analysis revealed that aluminum alloy has the minimum total deformation (0.0094 mm), improved thermal conductivity, and better heat dissipation than gray cast iron and magnesium alloy and hence is the most appropriate material to be used in manufacturing pistons. These results highlight the need for material selection and sophisticated analysis methods to achieve optimal piston design for improved engine performance and durability.

Keywords: FEA, Catia, Material Selection, Thermal & Structural Analysis.

Introduction:

The design, analysis, and optimization of pistons are essential for improving engine performance by achieving a balance between strength, weight reduction, and cost-effectiveness. This study employs CAD software like CATIA V5R16 for design and ANSYS for stress and thermal analysis, focusing on structural and thermal load management. By introducing design modifications, such as openings in the piston skirt, and optimizing parameters like barrel thickness and ring land width, the research demonstrates significant improvements in thermal performance and structural efficiency [1-2]. The stress distribution and thermal stresses in three aluminum alloy pistons using Finite Element Method (FEM) under operating gas pressure and temperature conditions. The study focuses on pistons for a four-stroke single-cylinder Bajaj Kawasaki engine, utilizing ANSYS 12.1 for static and thermal stress analysis to identify critical stress regions. The results aid in selecting the best aluminum alloy and optimizing piston geometry for enhanced performance and durability [3]. The stress distribution and thermal stresses in pistons made of five different materials—Al-SiC graphite, A7075, A6082, A4032, and AL-GHY 1250—using Finite Element Method (FEM) and mechanical property testing. The analysis, performed in ANSYS 15, focuses on a four-stroke single-cylinder Bajaj Kawasaki engine piston, evaluating structural and thermal performance under operating conditions. The results identify critical stress regions and help select the most suitable material for optimized piston design [4]. The surface behaviour of a single-cylinder four-stroke diesel engine with a CrN-coated cylinder applied via PVD, comparing it to an uncoated cast iron cylinder. The research examines wear behaviour, hardness, surface topography, microstructure, and running conditions, analyzing structural changes caused

by thermal and mechanical shocks using X-ray analysis. The findings provide insights into the performance and durability improvements offered by CrN coating in engine applications [5]. thermal efficiency of a diesel engine by analyzing temperature and thermal stress distributions in ceramic-coated steel alloy piston crowns. Using zirconium and silicon dioxide coatings with a 0.4mm thickness, the study compares coated and uncoated pistons through static and thermal analysis. Results show that ceramic coatings significantly increase surface temperature and improve thermal efficiency, with thicker coatings providing diminishing returns [6]. Enhancing engine performance through advanced piston design and material optimization is critical for improving thermal efficiency and durability in internal combustion engines. This study explores the application of Thermal Barrier Coatings (TBCs), such as MgZrO₃ and Ni-Cr-Al, on pistons using CATIA for 3D modelling and Finite Element Analysis (FEA) to evaluate stress, strain, deformation, and thermal distribution. By analyzing materials like Al-SiC, Ti64AlV, and AL4032, the research identifies optimal coating-material combinations to reduce thermal loads and enhance engine performance [7-9]. The pursuit of higher efficiency, lower fuel consumption, and reduced emissions in internal combustion engines has driven significant advancements in engine technology. Innovations such as thermal barrier coatings, HVOF coatings, and advanced computational methods like FEA and CFD have been employed to optimize engine performance and durability. However, there remains a gap in research regarding energy-saving techniques during the power stroke and internal coating methods, highlighting the need for further exploration in these areas [10]. Addressing thermal load challenges and stress distribution in pistons operating under high-temperature and high-load conditions is critical for enhancing engine performance and durability. This study employs advanced numerical methods, including thermos-mechanical decoupled FEM and Finite Element Analysis (FEA), using CAD tools like SolidWorks and CATIA, along with ANSYS for simulation. By analyzing stress concentration in critical areas such as the piston head, skirt, and sleeve, and comparing materials like Aluminum alloy and Cast Iron, the research aims to optimize piston design and material selection for improved thermal behaviour and stress management in high-end automotive applications [11-13]. this utilizes Computer-Aided Engineering (CAE) tools and Finite Element Analysis (FEA) to evaluate the structural and thermal behaviour of aluminum alloy pistons in combustion engines. By simulating conditions such as 330°C temperature and 5 MPa pressure, the research identifies high-stress regions and critical areas in piston components. The analysis includes both piston heads and assemblies with piston pins and connecting rods, aiming to optimize design and performance [14]. explores the design of an internal combustion engine piston by evaluating materials such as aluminum alloy, carbon graphite, and tungsten using finite element analysis. Structural and thermal calculations are compared to assess mechanical strength and heat transfer properties. Results suggest that carbon graphite and tungsten are viable alternatives to aluminum alloy, offering potential improvements in fatigue resistance and thermal performance [15]. design and analysis of pistons and combustion chambers, critical components in IC engines, using Catia V5 and ANSYS 18.1 software. Thermal and structural analyses are conducted on aluminum and magnesium alloys to evaluate their performance under high pressure, temperature, and stress conditions. Results reveal that magnesium-based alloys withstand higher pressure and stress but exhibit significant deformation, providing insights for optimizing engine design and material selection [16]. stress distribution and thermal stresses in pistons made of five materials—Al-SiC graphite, A7075, A6082, A4032, and AL-GHY 1250—using Finite Element Method (FEM) and mechanical property testing. Designed in CATIA V5 and analyzed in ANSYS 15, the research evaluates structural and thermal performance under operating conditions for a four-stroke single-cylinder Bajaj Kawasaki engine. The results identify critical stress regions and determine the most suitable material for optimized piston design [17]. stress distribution in various piston materials used in internal combustion engines, as mechanical stress is a leading cause of piston failure. By studying the performance of different materials under varying conditions, the study aims to enhance piston durability and reliability. The findings contribute to improving the overall efficiency and longevity of IC engines [18]. investigates the thermal behaviour of conventional and zirconium-coated diesel pistons using ANSYS for finite element analysis. The research focuses on optimizing mesh and reducing stress concentration in critical areas like the piston head, skirt, and sleeve under real engine conditions. By employing NX/CATIA for design and ANSYS for simulation, the study aims to enhance piston performance and durability through functionally graded coatings [19]. stress distribution and thermal stresses in pistons of five materials—Al-SiC graphite, A7075, A6082, A4032, and AL-GHY 1250—through Finite Element Method (FEM). Modeled in CATIA V5 and simulated in ANSYS 16.0, the study analyzes

structural and thermal performance under working conditions for a four-stroke single-cylinder Pulsar 220cc engine. The findings determine critical stress areas and identify the most appropriate material for optimized piston design [20-21]. This research studies stress distribution and thermal deformities in Mg-SiC composite pistons of different SiC volume fractions (10%, 20%, and 30%) through NX 11.0 modeling and ANSYS 19.2 structural and thermal analysis. The study compares the performances of current Al4032 and Al6061 pistons found in Bajaj Pulsar 150cc engines. The study endeavors to determine the best material content for enhanced piston performance and thermal and mechanical loads durability [22-23]. design and analysis of a piston for a 1300cc diesel car using Pro/Engineer for modeling and ANSYS for structural and thermal analysis. Three types of piston ring profiles are considered stress, displacement, thermal flux, and temperature distribution are studied under loaded conditions. The work compares materials such as Cast Iron, Aluminum Alloy A360, and Zamak to establish the most suitable one for the manufacture of piston and piston ring [24]. aluminum piston alloy improvement by adding 25 nm alumina (Al₂O₃) nanoparticles through the stir casting process. The introduction of Al₂O₃ NPs at 4 wt% greatly enhances wear resistance and fatigue strength by 12.13% and 67.5%, respectively, over pure aluminum. The findings show that Al₂O₃ NPs improve mechanical properties, with the best performance at 4 wt%, and thus it is a good material for high-performance piston applications [25].

MATERIALS AND METHODOLOGY:

Engine specifications:

The engine used for this work is a single cylinder four stroke air cooled type Bajaj pulsar 150 petrol engine. The engine specifications are given in below table.

Table – 1 Engine specifications

Parameters	Values	Parameters	Values
Engine type	Four stroke, petrol engine	Max Power	13.8 bhp @ 8,500 rpm
No. of cylinder	Single cylinder engine	Max Torque	13.25 Nm @ 6,500 rpm
Bore	56mm	Top Speed	110 kmph
Stroke	60.7mm	Compression Ratio	9.8 +/- 0.3:1
Displacement	149.5 cc	Mileage	47 kmpl

PROPERTIES OF MATERIALS AND SURFACE COATINGS:

MATERIALS:

Aluminum Alloy(A4032):

Aluminum alloys is lightweight and good thermal conductivity. They provide a compromise between strength and weight, enabling efficient heat dissipation without compromising structural integrity. Their wear resistance is moderate, and they tend to suffer from surface damage over time, so they are usually coated or treated to enhance durability. Aluminum alloys possess good corrosion resistance, which aids in their lifespan in engine surroundings. For all these reasons, aluminum alloys become the main substance for making pistons, and they offer an optimum blend of heat resistance, light weightiness, and strength.

Gray Cast Iron:

Gray cast iron is a light material but not very much of aluminum alloy and possesses outstanding wear resistance, making it a favorite for affordable and long-lasting engine parts. It possesses average thermal conductivity, which enables it to dissipate heat efficiently while being structurally sound. It also possesses great corrosion resistance, which further increases its lifespan in engine use. Because of these characteristics, the gray cast iron is widely employed in piston skirts and ring grooves, where wear resistance and economy are the chief considerations.

Magnesium Alloy:

Magnesium alloy is a very light material, and it is therefore very desirable for lightening the total weight of engine parts. Magnesium alloy has poor wear resistance and poor thermal conductivity, thus not being favourable for high-performance use. Though it possesses average corrosion resistance, its mechanical characteristics are not conducive.

Table – 2 Material properties

Property	Aluminum Alloy (Al4032)	Gray iron	Magnesium Alloy	Aluminum Alloy (Al6061)
Density(g/cm ³)	2.77	7.2	1.8	2.70
Young's modulus (Gpa)	71	110	45	68
Poisson's Ratio	0.33	0.28	0.35	0.33
Thermal conductivity(w/mk)	168	52	156	158

DESIGN MODEL:

The piston model is developed through CATIA software. The process of design starts with sketching the rudimentary 2D profile of the piston, establishing its critical dimensions like crown diameter, height, skirt length, and ring groove locations. Based on the Pad and Revolve tools, the 2D sketch is now converted to a 3D solid model. Other design features like fillets, chamfers, and cutouts are implemented through Part Design tools.

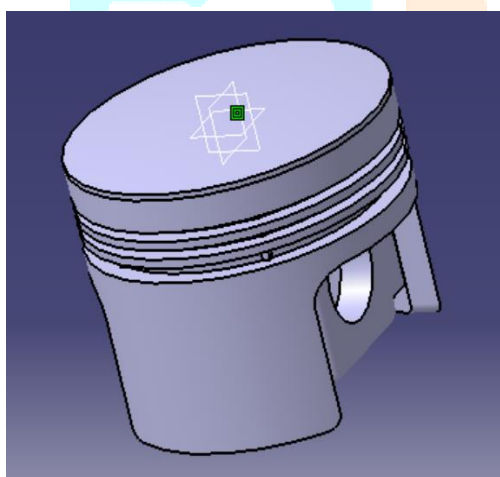


Fig – 1a Piston In Catia

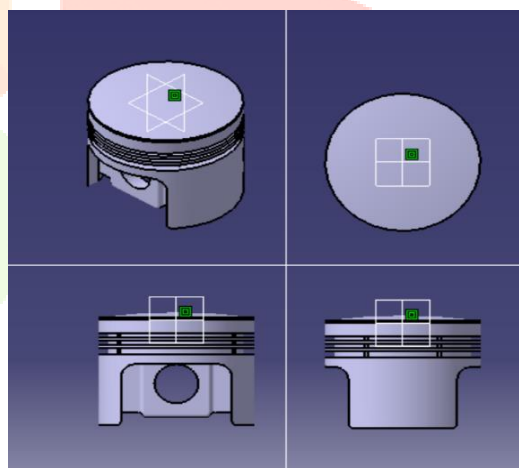


Fig – 1b Different Views Piston In Catia

EXPERIMENTATION:

Static Structural And Steady-State Thermal Analysis:

Static Structural and Steady-State Thermal Analysis are important steps in analyzing the performance of an IC engine piston. Static Structural Analysis determines the stress, strain, and deformation of the piston under mechanical loads like combustion pressure to find high-stress areas and guarantee structural integrity. Steady-State Thermal Analysis determines the temperature distribution and thermal stresses throughout the piston, taking into account heat developed during combustion. By integrating these analyses, the research guarantees that the piston withstands both thermal and mechanical loads, designing the piston for optimum durability and performance under actual working conditions.

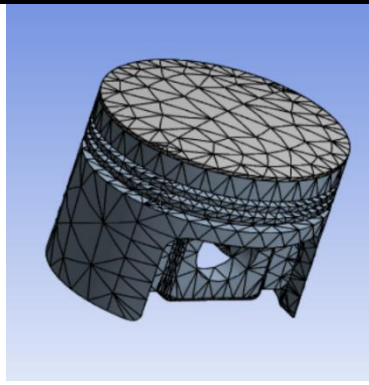


Fig – 2 Mesh Body

Boundary conditions of Static and Thermal analysis:

- Maximum pressure load at the top surface of the piston crown 5 mpa
- Piston hole area is fixed
- Temperature at the top surface of the piston crown 500 °c
- Convection of piston 5000 w/mm²

RESULTS AND DISCUSSION:

Static structural analysis:

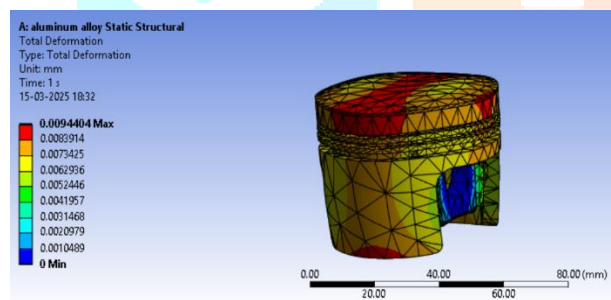


Fig – 3a Total deformation of Aluminum alloy

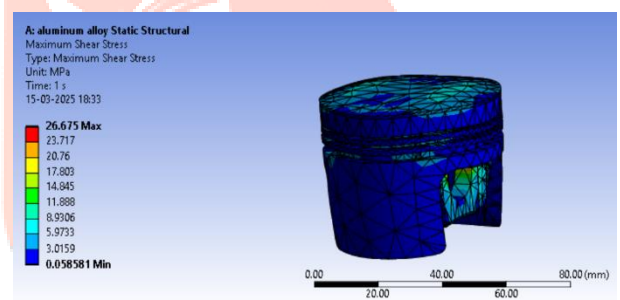


Fig – 3b Shear stress of Aluminum alloy

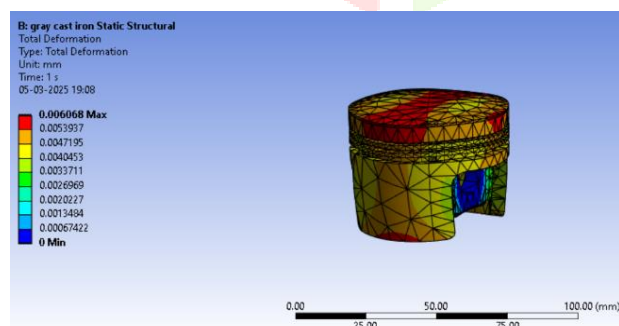


Fig – 4a Total deformation of Gray cast iron

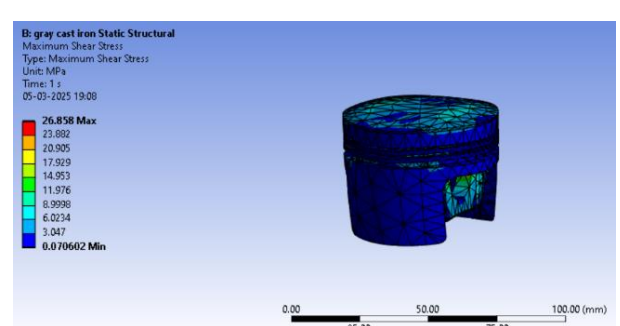


Fig – 4b Shear stress of Gray cast iron

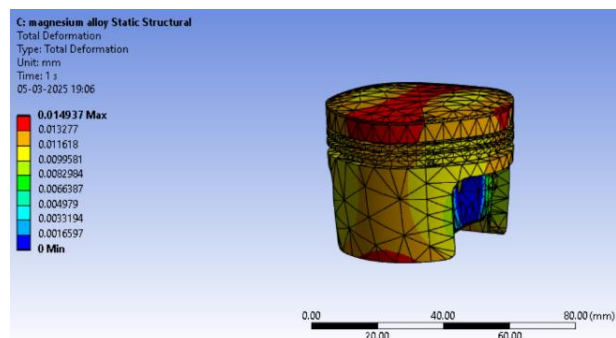


Fig – 5a Total deformation of Magnesium

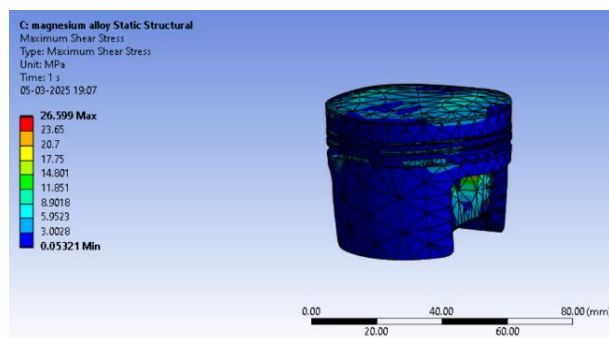


Fig – 5b Shear stress of Magnesium alloy

Steady state thermal analysis:

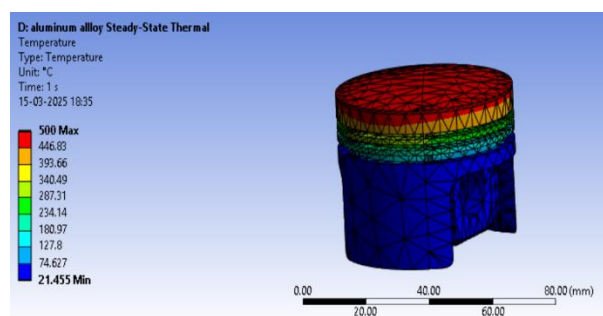


Fig – 6a Temperature of Aluminum alloy

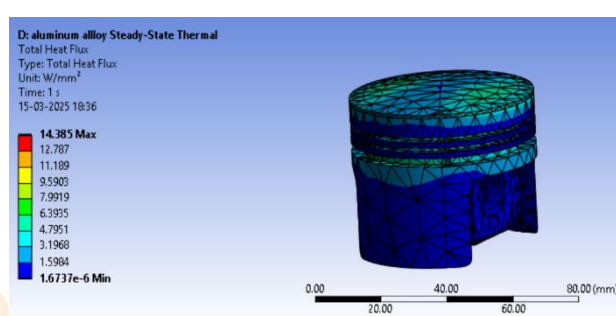


Fig – 6b Total heat flux of Aluminum alloy

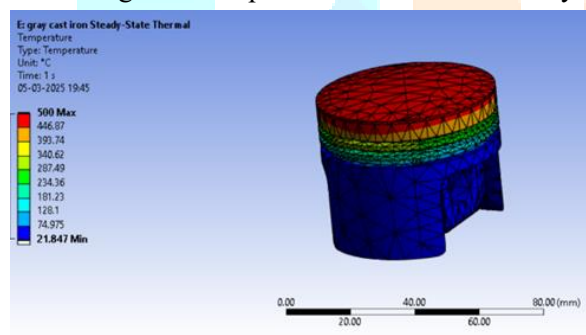


Fig – 7a Temperature of Gray cast iron

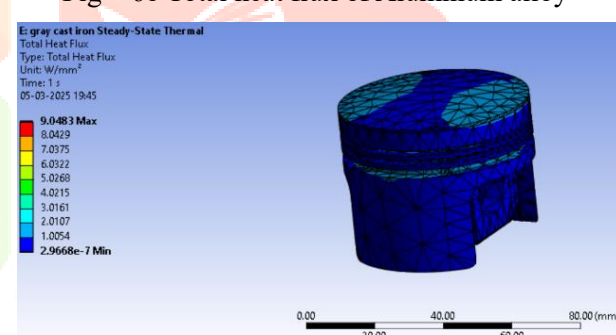


Fig – 7b Total heat flux of Gray cast iron

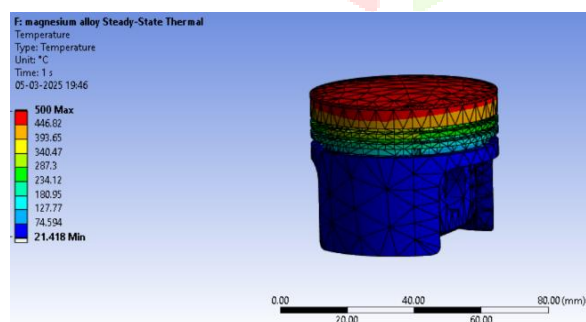


Fig – 8a Temperature of Magnesium alloy

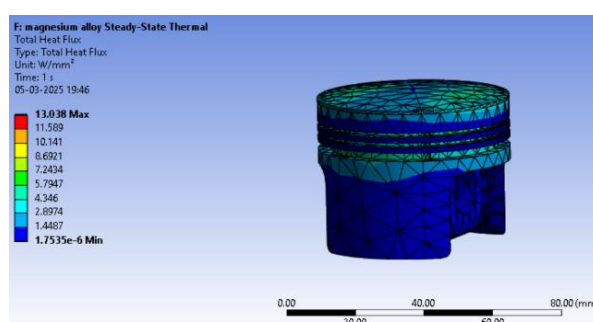


Fig – 8b Total heat flux of Magnesium alloy

Table – 3 Materials readings

Materials	Total Deformation max (mm)	Shear Stress max (mpa)	Temperature min (°c)	Total Heat Flux max (w/mm ²)
Aluminium Alloy (A14032)	0.0094	26.67	21.45	14.38
Gray Cast Iron	0.0060	26.85	21.84	9.04
Magnesium alloy	0.0149	26.59	21.41	13.03

Static structural analysis:

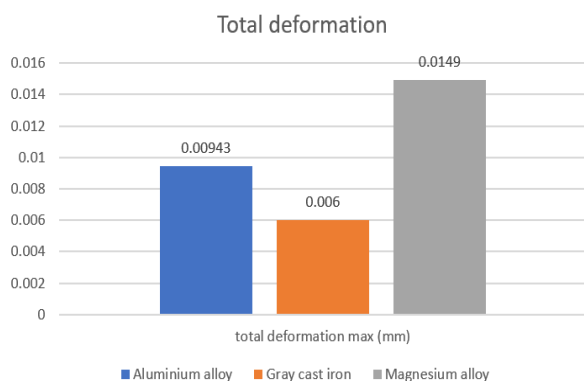


Fig – 5a Total deformation

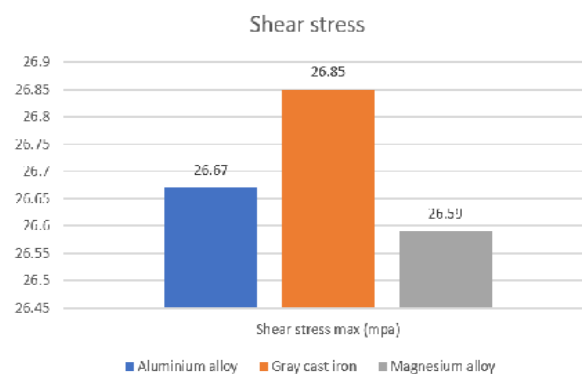


Fig – 5b Shera stress

Steady state thermal analysis:

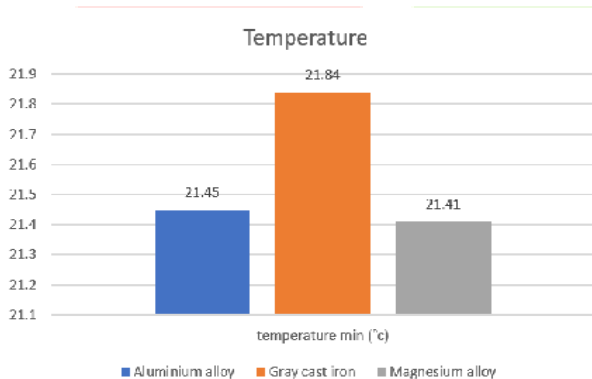


Fig – 6a Temperature

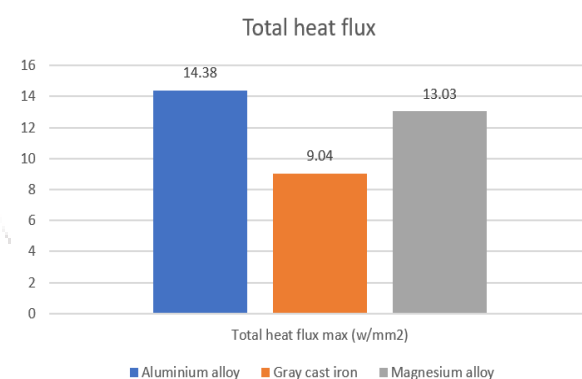


Fig – 6b Total heat flux

The static structural and thermal analysis offered crucial information regarding the material and coating behaviour. The observations are as follows:

Deformation Analysis: Among the material analyzed, aluminum A14032 alloy had the least total deformation (0.0094 mm), Which made it the most suitable for structural stability.

Shear Stress Analysis: Shear stress level was almost the same in different materials, with aluminum A14032 alloy being 26.67mpa, gray cast iron 26.85 mpa and magnesium alloy 26.59 mpa.

Thermal Analysis: The aluminum A14032 alloy piston had a minimum temperature of 21.45°c, which was superior to gray cast iron and magnesium alloys in heat dissipation.

Heat Flux Analysis: The maximum total heat flux was found to be in aluminum alloy (14.38 w/mm²), which reflects high thermal conductivity and effective heat transfer.

COMPARISON TO THE ALUMINUM ALLOY(Al6061) AND (Al4032):

Materials	Total Deformation max (mm)	Shear Stress max (mpa)	Temperature min (°c)	Total Heat Flux max (w/mm ²)
Aluminium Alloy (Al4032)	0.0094	26.67	21.45	14.38
Aluminium Alloy (Al6061)	0.39952	2332.8	379.05	0.0721

CONCLUSION:

The analysis and design of an IC engine piston for the Bajaj Pulsar 150 engine, considering three materials: aluminum Al4032 alloy, gray cast iron, and magnesium alloy. With CATIA for 3D modelling and ANSYS for structural and thermal analysis, the study sought to identify the best material for piston manufacturing considering deformation, shear stress, temperature distribution, and heat flux.

The outcome confirmed that aluminum Al4032 alloy had the minimum total deformation (0.0094 mm) and better thermal conductivity, thereby being the best material for heat dissipation as well as structural stability. Gray cast iron, as it had a good resistance to wear, had greater deformation and poorer thermal performance than aluminum alloy. Magnesium alloy, though possessing lighter characteristics, had lower thermal conductivity and greater deformation, thus not being an ideal choice for applications requiring better performance.

The thermal analysis also verified that aluminum Al4032 alloy possessed the lowest temperature (21.45°C) and highest heat flux (14.38 W/mm²), which shows effective heat transfer and dissipation. Gray cast iron and magnesium alloy, on the other hand, had higher temperatures and lower heat flux, thus being less efficient in thermal load management.

In comparison with aluminum alloy Al6061[22], Al4032 performed much better in deformation, shear stress, and thermal conductivity. Al6061 showed much greater deformation (0.39952 mm) and less heat flux (0.0721 W/mm²), further supporting the superiority of Al4032 for piston use.

In summary, aluminum alloy Al4032 is the best material for the manufacture of pistons based on its best combination of structural strength, heat conductivity, and thermal dissipation. The research stresses the significance of material selection and sophisticated analysis methods in the design of pistons for enhancing engine performance, longevity, and efficiency. Further studies might consider the application of advanced coatings and composite materials in enhancing piston performance for extreme operating conditions.

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