Numerical Study of Flat-top Piston Head Structure Under Different Materials

Hendry Sakke Tira*, Muhammad Ponco Zulfikar, I Made Adi Sayoga
Department of Mechanical Engineering, Faculty of Engineering, University of Mataram
Jalan Majapahit No 62, Mataram 83115 Nusa Tenggara Barat Indonesia
*hendrytira@unram.ac.id

Abstract

Piston is an important component of two-wheeler since it is able to generate high pressure and convey combustion energy into crank rotation. Piston is typically made of aluminium alloy and other materials that can endure extremely high pressure and heat on the surface during combustion. Aluminium alloy and magnesium alloy are two distinctive materials that are frequently used in piston head. The objective of this study is to use numerical analysis to investigate and analyse a flat-top piston head made of two different materials. The design process allows usage Solidworks software, and the analysis process makes use of Ansys software. The Ansys simulation is intended for evaluating the maximum stress, total deformation variability, and safety factor for each material analysed. The findings from the analysis indicate that the deformation of the piston head made of aluminium alloy is smaller than that of magnesium. Whereas the aluminium alloy has a lower safety factor than magnesium. The von Mises stresses for the two materials, however, are essentially equal.

Keywords: aluminium alloy; flat-top piston head, magnesium alloy; numerical analysis

Abstrak

Piston merupakan komponen penting kendaraan roda dua karena mampu menghasilkan tekanan tinggi dan menyalurkan energi pembakaran kepada putaran engkol. Piston biasanya terbuat dari paduan aluminium dan bahan lain yang dapat menahan tekanan dan panas yang sangat tinggi di permukaan selama proses pembakaran. Paduan aluminium dan magnesium adalah dua bahan yang sering digunakan pada kepala piston. Tujuan dari penelitian ini adalah untuk menganalisis kepala piston berbentuk rata yang terbuat dari dua bahan yang berbeda menggunakan analisis numerik. Proses desain menggunakan perangkat lunak Solidworks, dan proses analisis menggunakan perangkat lunak Ansys. Simulasi Ansys dimaksudkan untuk mengevaluasi tegangan maksimum, variabilitas deformasi total, dan faktor keamanan untuk setiap material yang dianalisis. Temuan dari analisis menunjukkan bahwa deformasi kepala piston yang terbuat dari paduan aluminium lebih kecil daripada magnesium. Demikian juga paduan aluminium memiliki faktor keamanan yang lebih rendah daripada magnesium. Namun demikian untuk tekanan von Mises kedua bahan tersebut memiliki nilai yang relatif sama.

Kata kunci: *analisis numerik; paduan aluminium; paduan magnesium; piston kepala rata*

1. Introduction

One of the important components in the engines is the piston. Piston is located inside the cylinder block which functions to generate power when the engines is operating. The power generated is obtained by receiving pressure from the combustion of fuel and oxidants. The explosion caused a strong piston movement from top dead centre to bottom dead centre. The power received by the piston is then transmitted to the crankshaft via the connecting rod [1]. Given the considerable amount of pressure and temperature received by the piston, it is one of the most critical components that necessitates special attention and care [2].

It is not unexpected for the piston to fail and burn out because of the enormous pressure. Failure and exhaustion of the piston can result in negative consequences such as loss of engine power and engine overheating. This results in higher maintenance costs to restore damaged pistons [3]. As a result, in preparatory work for manufacture, the piston must be designed to have an operating pressure that corresponds to the strength of the constituent material.

The piston itself can be made in a variety of ways, including squeeze casting, investment casting, and sand casting [4]. The most crucial aspect of all of these piston manufacturing methods is to avoid the formation of products with porosity and/or excess dimensions. Porosity is a condition in which gas is trapped in molten metal during the casting process, leading to the development of small holes both on the inside and on the surface [5]. If this piston production defect is not handled properly it will reduce the strength of the material and also release excess heat which results in increased fuel consumption [6]. The occurrence of this production record necessitates the need for additional machining processes, which raises production costs.

Having known that the manufacturing procedure for pistons appears to require a significant investment and has the potential for failure, the finite element analysis method can be one of the solutions. Using this approach as an evaluation method, a large and complex analysis can be calculated easily and quickly [7]. This method has also been used to analyse other vehicle components such as twin-spark plug arrangement, combustion chamber shapes with the same compression ratio, nozzle types, piston bowl geometry, intake valve timing [8-12].

Based on previous research findings, no articles have attempted to analyse the structure of a piston head with a flat crown profile. As a result, the objective of this study is to use numerical methods to determine the maximum stress, maximum deformation, and safety factor of a piston head with a flat-top piston head made of a variety of materials, such as aluminium alloy and magnesium alloy.

2. Materials and methods

The purpose of this research is to quantify the stress, deformation, and safety factor on a flat piston head made of a variety of materials, including aluminium alloy and magnesium alloy, which experience mechanical loads during the expansion stroke throughout the form of gas pressure from combustion. The finite element method was used to perform the analysis numerically. It is assumed that the piston operates independently and only receives mechanical load, with no influence from operating temperatures.

2.1 Material

Aluminium alloy is a common material for piston heads. This material was chosen because it is fairly affordable but has good strength. It is typically used in engines with cylinder capacities ranging from 100 to 150 cc [13]. The use of aluminium and magnesium alloys will be compared in this study. Furthermore, table 1 shows the characteristics of the material to be evaluated.

Table 1. Properties of aluminium and magnesium alloys

Property	Material	
	Aluminium alloy	Magnesium alloy
Density	2770 kg/m3	1800 kg/m3
Modulus young	71000 MPa	45000 MPa
Poison ratio	0,33	0,35
Bulk Modulus	69608 MPa	50000 MPa
Shear Stress	26692 MPa	16667 MPa
Yield Strength	280 MPa	193 MPa
Tensile ultimate strength	310 MPa	255 MPa

2.2 Piston head design

The piston specifications analysed are coherent with the piston specifications commonly found in Honda Revo F1 two-wheeled vehicles in 2014. Table 2 lists the specifications for the two-wheeler. Figure 1 depicts the dimensions of the piston head.

Table 2. Honda Revo F1 2014 engine specifications

Engine specification	Data
Number of cylinders	1
Engine cycle	4-stroke
Number of valves	2
Displacement volume	109,17 cm^3
Bore/stroke	50mm/55,6 mm
Compression ratio	9,3:1
Rated power	6,56 kW at 7.500 rpm
Peak torque	8,76 Nm at 6.000 rpm

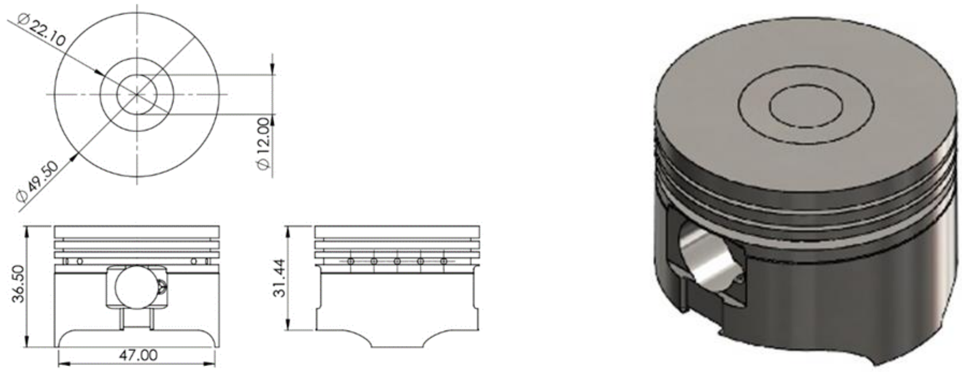


Figure 1. Honda Revo F1 2014 piston head dimensions

2.3 Boundary conditions

In this piston head assessment, static structural analysis is used to determine structural changes in stress and deformation when a constant load is applied. The support for testing is located inside the two piston head support holes (Fixed Supports). The boundary condition imposed on the piston crown in these models is that the piston is subjected to an average effective pressure regardless of combustion temperature. Equation 1 shows the equation for calculating the average effective pressure using a known torque [14].

$$MEP = \frac{6,28 \times n_R \times T}{Vd} \text{ (kPa)} \quad (1)$$

Where:

MEP	: Mean effective pressure (kPa)
n_R	: Number of Revolution (4-Stroke Engine ; n_R =2)
T	: Torque (Nm)
Vd	: Displcament volume

Based on the data, the torque value is 8.76 Nm and the displacement volume is 0.109 dm^3, implying that the average effective pressure is 1009 kPa, or 1 MPa. Static analysis is used to determine how the numerical model's boundary conditions and some important parameters are used. Figure 2 depicts the static analysis boundary conditions provided by Ansys software.

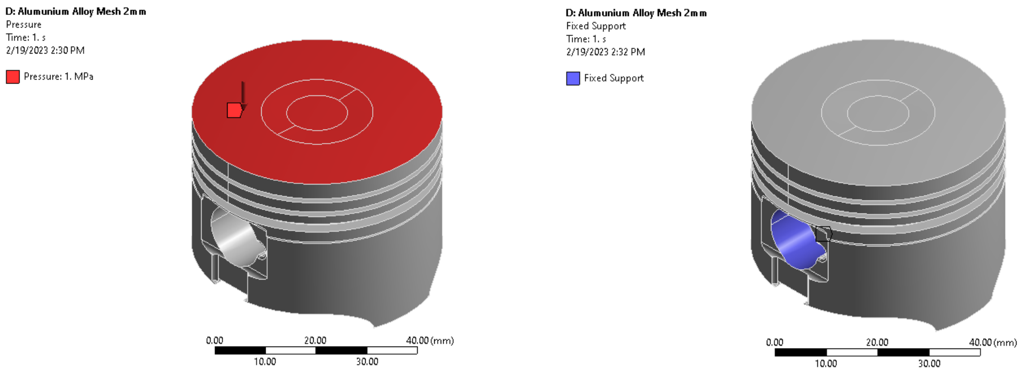


Figure 2. Provision of fixed support on the piston head

In this study, the mesh shape was determined to be tetrahedral, and the element size was determined to be 2 mm, resulting in a total of 26463 elements and 47373 nodes with an aspect ratio of 2.78. The mesh arrangement that has been developed is shown in Figure 3.

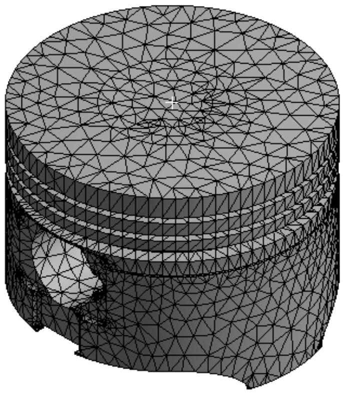
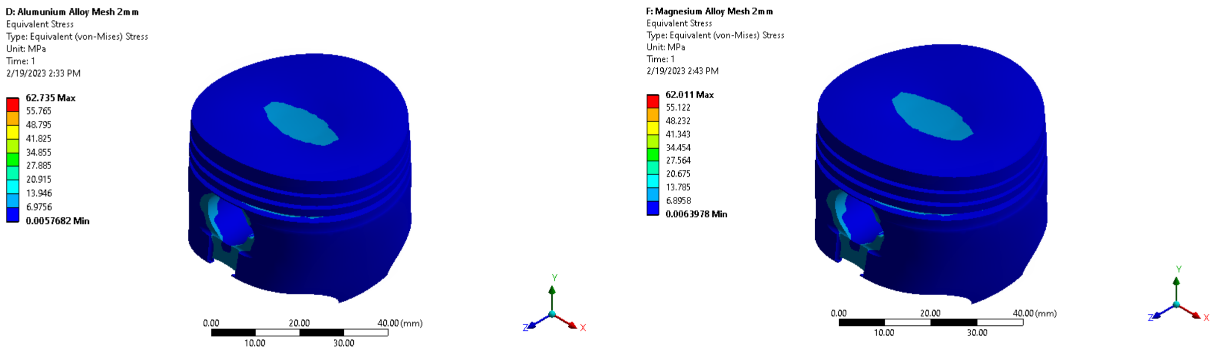


Figure 3. Mesh on piston head

3. Results and discussion

3.1. Von mises stress

According to the results of the static structural stress simulation, the range of stresses experienced in aluminum alloy ranges from 0.0057682 to 62.73 MPa, with an average stress of 4.918 MPa. Meanwhile, the stress in magnesium alloy ranges from 0.0063978 to 62.01 MPa, with an average stress of 4.911 MPa (Figure 4). Based on these findings, it was discovered that both materials experienced relatively the same maximum and average stress, despite the fact that aluminum alloy had a slightly higher stress value than magnesium alloy. This demonstrates that the difference in piston material has no impact on the degree of static stress received by the flat crowned piston head in the combustion chamber due to the combustion process. The amount of structural static pressure received is solely determined by the cross-sectional area of the piston head surface.



3.2. Deformation

The aluminium piston head deformation has a maximum value of 0.007425 mm and an average value of 0.0023924 mm. In magnesium alloy, it is 0.011763 mm, with a mean of 0.0037943 mm (Figure 5). These findings indicate that magnesium deforms more than aluminium. The deformation that occurs is determined by the properties of each material. The red colour indicates that the part is highly deformed. The higher deformation value of magnesium is caused, among several other factors, by magnesium density, which is only two-thirds that of aluminium. Furthermore, magnesium melting and boiling points are lower than those of aluminium [15]. Due to the various physical properties of magnesium, pistons made of magnesium alloy are more susceptible to physical changes caused by the high in-cylinder pressure generated during the combustion process.

The high deformation occurs underneath the mic point in the area of the slipper skirt or piston slipper. This is due to the shape of the part that protrudes out with a slightly larger area, which allows it to change shape easily with a little pressure applied. The main objective of the part is to reduce the reciprocating mass, allowing the engine to be balanced more easily and thus allowing for higher speeds [16].

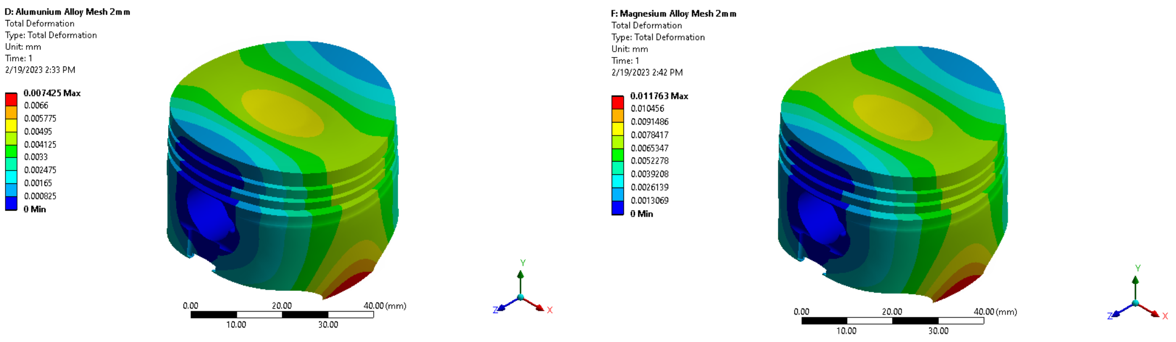


Figure 5. Total deformation in aluminium and magnesium alloys

3.3. Safety factor

On such a design where the material type is known, the safety factor can be determined against the yield stress under certain environmental conditions and loads where the minimum standard value is 1.5 - 2 [17]. The safety factor applied to the workpiece is determined based on the ratio of the yield strength to the maximum von Mises stress from the simulation results which can be expressed as in equation 2 [18].

$$\text{Safety Factor} = \frac{\sigma_{\text{yield strength}}}{\sigma_{\text{Von Mises}}} \quad (2)$$

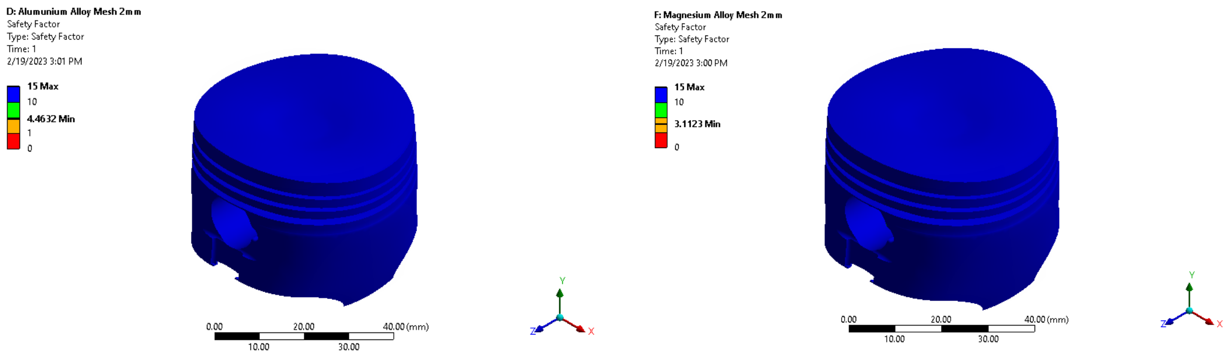


Figure 6. Safety factor of the piston head

The piston head safety factor for magnesium alloy is the lowest, at 3.11. Despite being made of aluminium alloy, the piston head has a safety factor of 4.46 (Figure 6). These results indicate that both materials are suitable for use as piston head materials because they have a safety factor greater than that allowed. Furthermore, even though the von mises stress values of the two materials are assumed to be identical, the aluminium alloy has a higher safety factor than magnesium alloy. This demonstrates that aluminium alloy has a higher yield strength value than magnesium alloy. This is directly related to the fact that aluminium is stronger than magnesium [15].

4. Summary

Through the simulation and analysis, it is possible to draw the conclusion that the magnitude of the maximum von Mises stress on a flat-top piston head is unaffected by its constituent material. The stress values of the two materials tested are nearly identical. However, the results of the deformation test and the safety factor were different. The different in physical properties of the two test materials are evidenced to be a factor influencing the obtained deformation value and safety factor. Aluminium is more suitable for flat-top piston heads due to its higher strength, boiling point, melting point, and density values than magnesium.

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