Simulation of Heat Transfer Rate in Motorcycle Engine Cylinder with Variation of Distance Between Fins and Material

Mohamad Zainal Abidin[1], Sugeng Hadi Susilo [2]✉

[1,2] *State Polytechnic of Malang,, Indonesia*

**Author Email: mohamadzainalabidin28@gmail.com, sugeng.hadi@polinema.ac.id*

Article Information

Manuscript Received 2023-07-20
Manuscript Revised 2023-08-07
Manuscript Accepted 2023-09-01
Manuscript Online 2024-04-03

ABSTRACT

Cylinder blocks on motorcycles that do not use a radiator cooling mechanism generally use a fin mechanism around the motorcycle cylinder block. Fins on motorcycles are useful for spreading the heat from combustion from the inside out, so that the engine temperature does not heat up quickly. During the combustion process in the cylinder block can cause heat with a high temperature. If this heat is not immediately distributed around it will cause excessive heat and will cause over heating on the motorcycle, which can interfere with the performance of the motorcycle. Thermal analysis is often used to study heat transfer on many surfaces including fins, cylinder block of an internal combustion engine and also the material of the mold block. The engine cylinder with fins was designed using Autodesk Fusion 360 with different spacing between fins of 10 mm, 8 mm, 6 mm and 4 mm. The materials used for modeling in this study are Al 356 (cast alloy), AA 2014T6 (Wrought alloy), AA 1060 (Wrought alloy), cast iron with 2% nickel, AM60A-F (Cast alloy), Magnesium alloy (AZ63A), Aluminum 6061, Gray cast iron grade 20, Al 360 (cast alloy), Al 380 (cast alloy). The simulation results of the engine cylinder block made of cast iron with 2% nickel with fins having a spacing between fins of 4 mm and a cylinder perforation diameter of 4 mm on the fins are most suitable for a better heat transfer rate compared to the other materials used in this study.

Keywords: *Cylinder block, fin spacing, heat transfer, perforation, Simulation*

1. INTRODUCTION

Cylinder blocks on motorcycles that do not use a radiator cooling mechanism generally use a fin mechanism around the motorcycle cylinder block. Fins on a motorcycle are useful for spreading the heat from combustion from the inside out, so that the engine temperature does not heat up quickly. Motorcycle cylinder blocks are generally made of cast iron alloy and aluminum alloy materials. During the combustion process in the cylinder block can cause heat with a high temperature. If this heat is not immediately distributed around it will cause excessive heat and will cause over heating on the motorcycle, which can interfere with the performance of the motorcycle. Thermal analysis is often used to study heat transfer in many surfaces including fins, cylinder blocks of internal combustion engines and including the material of the mold block.

Ada banyak penelitian yang dilakukan pada efek There are many studies conducted on the effect of materials or materials used to make engine cylinder blocks, the effect of fin geometry and the effect of perforation on fins to determine the heat transfer rate of the engine [1]. This study discusses the thermal analysis of motorcycle cylinder blocks with fins made of cast iron, with aluminum alloys A356, A360, A380, AA6061, magnesium alloy and gray cast iron FG250 and aluminum metal matrix composite (Al-MMC). The results of his research found that the temperature difference or heat distribution decreased in the cylinder block with fins made of gray cast iron, magnesium alloy and A380 aluminum alloy. In the study, better heat transfer was found in the gray cast iron cylinder block due to its higher density.

Research on the effect of different shapes of perforations in fins on heat transfer rate. Different perforation geometries such as circular, rectangular, triangular and unperforated fins were used in the study. It was found that circular perforations had the highest heat transfer rate followed by rectangular perforations and triangular perforations and the minimum heat transfer rate was observed in unperforated fins [2].

Machine simulation with circular and rectangular geometry fins made of aluminum alloy A204 and aluminum alloy AA6061. The selected fin thicknesses are 2 mm, 2.5 mm and 3 mm and it can be generated that the better heat transfer rate is achieved in the circular fins made of AA6061 aluminum alloy. Circular fins of 2 mm and 3 mm thickness showed almost the same heat transfer capacity in both alloys [3].

Research on thermal analysis of Bajaj Caliber motorcycle engine model having rectangular fin geometry with curved shape. The model is made of different aluminum alloys such as AA6061, AA2014 and C443 aluminum alloy by increasing the fin tip thickness to 3 mm and providing slots of different sizes. The result of the study was that AA2014 with a slot size of 7.5 mm showed the highest heat transfer rate compared to other fins having slot sizes of 5 mm and 10 mm [4].

Research on heat transfer analysis of rectangular fin arrays with 2 mm and 3 mm diameter circular perforations. Tests were conducted in a wind tunnel under turbulent conditions. It was reported that the heat transfer rate increased with the increase in the number of perforations along the fin [5].

Research on the effects of different shapes of perforations in fins on heat transfer rate. Different perforation geometries such as round, rectangular, triangular and unperforated fins were used in the study. It was found that circular perforations had the highest heat transfer rate followed by rectangular perforations and triangular perforations and the minimum heat transfer rate was observed in unperforated fins [6].

Seeing from these studies, researchers try to modify the cylinder block by combining the groove width and perforation diameter on the engine fins with different material variations or materials. The modification serves to determine the best heat transfer rate for the air conditioning system on a motorcycle.

1.1 Cylinder Block

The Cylinder Block is one of the tools on a static motor which functions as a place for the piston to move in carrying out the motor work process. The function of the cylinder block is as a place to produce heat energy from the combustion process. The motorcycle cylinder block is the main part of a motorcycle, other parts of the motor are paired in or on the cylinder block, so that a complete motor arrangement is formed. In this cylinder block there is a smooth-walled cylinder hole, where the piston moves back and forth and on the side of the cylinder block fins and cooling water coat holes are made which are used for motor cooling [7].

1.2 Cylinder Block Material

1. Al 356 (cast alloy)

A356 is a type of aluminum alloy for casting. A356 die casting aluminum alloy has good casting and machining performance, suitable for use in automotive, aircraft, pump housings, impellers, high-speed blowers and other structural castings that require high strength. Aluminum A356 is often used to make complicated and complex aluminum castings, which provides light weight, pressure tightness and good mechanical properties [9].

2. AA 2014T6 (Wrought alloy)

AA 2014-T6 is 2014 aluminum with a T6 temper. To achieve this temper, the metal is artificially heat treated until it meets the standard mechanical properties requirements. This 2014 T6 aluminum can be used for applications that include its use at high temperatures and heavy-duty components, such as in the automotive industry and aerospace industry [10].

3. AA 1060 (Wrought alloy)

AA 1060 is an aluminum alloy formed from a combination of aluminum and other elements. By controlling the amount of certain alloying elements added. Aluminum 1060 has strength, properties, shape, and corrosion resistance that can be tailored to a variety of applications. AA 1060 is known for its excellent electrical and thermal conductivity, making it ideal for use in electronics, but also very strong and ductile for use in components such as turbine blades or aircraft and vehicle parts [11].

4. Cast iron with 2% Nickel

2% nickel cast iron is a group of carbon alloys containing 2% nickel, 2 - 4% carbon and varying amounts of silica and manganese. Cast iron also contains impurities such as phosphorus and sulfur. Cast iron is produced by reducing iron ore in a blast furnace and the main ingredient is pig iron produced from iron ore smelted in the furnace. The addition of 2% nickel to cast iron provides corrosion resistance. Applications of cast iron are common in the engineering world such as mechanical engineering, construction sites, woodworking, etc. [12].

5. AM60A-F (Cast alloy)

AM60A-F is categorized as Magnesium Alloy. It is usually used in die casting. AM60A-F magnesium cast alloy is known to have superior energy absorption characteristics and excellent ductility. It has slightly higher strength than that of magnesium AM50A, but other properties are similar. It is not resistant to saltwater conditions

6. Magnesium alloy (AZ63A)

Magnesium AZ63A adalah paduan magnesium. Magnesium AZ63A is a magnesium alloy. AZ63A is the ASTM designation for this material. AZ63A magnesium alloy is used as an advanced structural material in applications, particularly the automotive, aerospace, and railroad industries due to its unique properties of low density, good machinability, excellent damping capacity, and high specific strength [13].

7. Aluminum 6061

Aluminum 6061 is a precipitation-hardened alloy, which means it is strengthened during a heat treatment process that involves melting of particles in the grain structure of the metal, barrier movement and effectively increasing strength and durability. Applications of Aluminum 6061 include aerospace, aircraft, and automobiles due to its outstanding strength-to-weight ratio, good ductility, corrosion resistance, and crack resistance in adverse environments [14].

8. Gray cast iron grade 20

Gray cast iron grade 20 is gray cast iron in the as-fabricated condition (without tempering or treatment). This material grade has poorer tensile strength, ductility, and toughness than cast steel and ductile iron, so it is the worst cast iron considering its mechanical properties. However, it has good casting properties, shock absorption, wear-resistant properties and machining performance. This material is very suitable for the machining industry and automotive industry [15].

9. Al 360 (cast alloy)

A360 is an aluminum alloy with excellent pressure tightness and fluidity. It has a high silicon content and offers high corrosion resistance as well as high strength, even at high temperatures. Therefore, this material is very suitable for the automotive and marine industries [16].

10. Al 380 (cast alloy)

A380 is a common type of aluminum alloy in die casting, with great casting performance and some excellent mechanical and thermal properties, as well as good economy. It exhibits excellent fluidity, pressure tightness, and resistance to hot cracking, which makes it suitable for the aerospace industry. Applications of A380 include automobile parts, industrial parts, engine brackets, gearbox cases, and building tools. A380 is an ideal material for aluminum die casting. A380 aluminum is strong at high temperature and corrosion resistant, can maintain complex shapes and high accuracy [17].

1.3 Fins

Fins are a component that serves to accelerate the rate of heat transfer by expanding the surface of the object. When an object experiences convection heat transfer [18]. the heat transfer rate of the object can be accelerated by installing fins so that the surface area of the object is wider and the cooling process can be faster. Fins have various shapes to suit your needs. Perforation is a hole design given to the engine cylinder block fins to accelerate the rate of heat transfer [19].

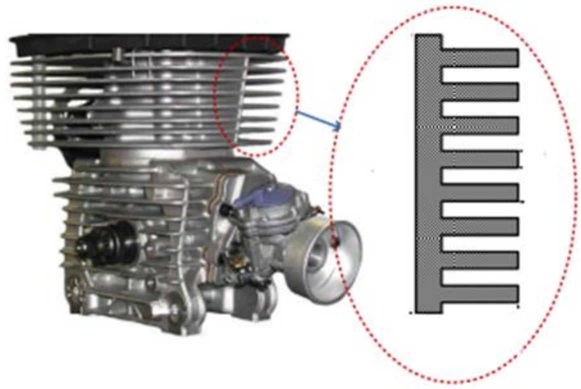


Figure 1. Fins

2. RESEARCH SIGNIFICANCE

The continuous combustion process in the engine results in a very high temperature condition. Very high temperatures will result in the design of the engine becoming uneconomical, most engines are also in an environment that is not too far from humans, thus reducing the safety factor. Very low temperatures are also not very favorable in the engine work process. A cooling system is used so that the engine temperature is maintained at the ideal working temperature limit. In this system, the engine heat is directly released into the air. An engine with an air cooling system has a design on the engine cylinder with cooling fins. Fins are an important component to increase the convection heat coefficient and heat transfer rate releasing heat to the atmosphere through forced convection. . The heat transfer rate depends on wind speed, geometry, surface area and ambient temperature [20].

3. RESEARCH METHODS

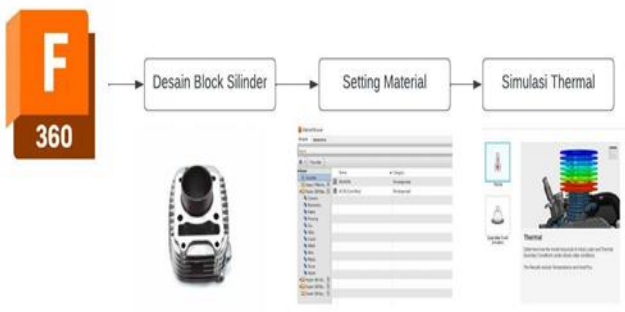


Figure 2. Simulation Setting

In this study, the data collection method is used to simulate the design of the cylinder block to obtain the results of the heat transfer temperature of the independent variables of the distance between the fins, the addition of perforations and the type of material. The following is the method of data collection.

1. Distance Between Fins
   - Designing a 150 cc cylinder block with variations in the distance between fins 4 mm, 6 mm, 8 mm, 10 mm using Autodesk Fusion 360 software.
   - Determine the simulation to be carried out (thermal simulation)
   - Determine the material to be used
   - Set the temperature on the cylinder
   - Set the outside air temperature
   - Determine the contact on the cylinder block
   - Defining Mesh
   - Perform simulation
   - Obtain simulation results
   - Collecting simulation result data
   - Perform analysis
2. Material Type
   - Looking for basic thermal data from the material to be used
   - Inputting basic thermal material data in autodesk fusion 360
   - Then each material will be inputted into the 150 cc cylinder block design on the variable distance between fins and perforations to be simulated.
   - Set the temperature on the cylinder
   - Set the outside air temperature
   - Determining contact on the cylinder block
   - Defining Mesh
   - Perform simulation
   - Obtain simulation results
   - Collecting simulation result data
   - Perform analysis

Tabel 1. Data Material

Material Type	Material Properties					
	Density	Young's Modulus	Poisson's Ratio	Thermal Conduktivity	Thermal Expansion coefficient	Specific Heat
Al 356	2.670 g/cm³	72.400 GPa	0,33	1.510E+02 W/(m·K)	21.400 µm/(m·°C)	0.963 J/(g·°C)
AA 2014T6	2.789 g/cm³	72.400 GPa	0,33	1.540E+02 W/(m·K)	23.000 µm/(m·°C)	0.897 J/(g·°C)
AA 1060	2.700 g/cm³	72.400 GPa	0,33	1.510E+02 W/(m·K)	21.400 µm/(m·°C)	0.963 J/(g·°C)
Cast iron with 2% Nickel	7.150 g/cm³	90.000 GPa	0,3	2.100E+01 W/(m·K)	12.000 µm/(m·°C)	0.540 J/(g·°C)
AM60A-F	1.800 g/cm³	45.000 GPa	0,35	6.100E+01 W/(m·K)	26.000 µm/(m·°C)	1.000 J/(g·°C)
Magnesium alloy (AZ63A)	1.827 g/cm³	44.816 Gpa	0,34	6.510E+01 W/(m·K)	25.200 µm/(m·°C)	1.020 J/(g·°C)
Aluminum 6061	2.700 g/cm³	68.900 GPa	0,33	1.670E+02 W/(m·K)	23.600 µm/(m·°C)	0.901 J/(g·°C)
Gray cast iron grade 20	7.395 g/cm³	81.496 Gpa	0,23	4.804E+01 W/(m·K)	12.996 µm/(m·°C)	0.450 J/(g·°C)
Al 360	2.630 g/cm³	71.000 GPa	0,39	1.130E+02 W/(m·K)	21.000 µm/(m·°C)	0.962 J/(g·°C)
Al 380	2.760 g/cm³	75.000 GPa	0,33	1.090E+02 W/(m·K)	21.800 µm/(m·°C)	0.963 J/(g·°C)

Material selection is a very important consideration to improve the performance and life of the cylinder block. Any cylinder block material must contain high thermal conductivity, relatively low density, must be strong to operate at high temperatures, good corrosion and abrasion resistance. Motorcycle cylinder blocks are generally made of cast iron alloy and aluminum alloy materials. Standard original motorcycle manufacturers generally use cast iron alloy material because it is more resistant to rust, has good heat resistance, economic factors (cheap) and has high thermal conductivity. Cylinder block specifications specify the correct hardness range, chemical composition, tensile strength and other properties required for the intended use. Material property data is addressed in table 1. above.

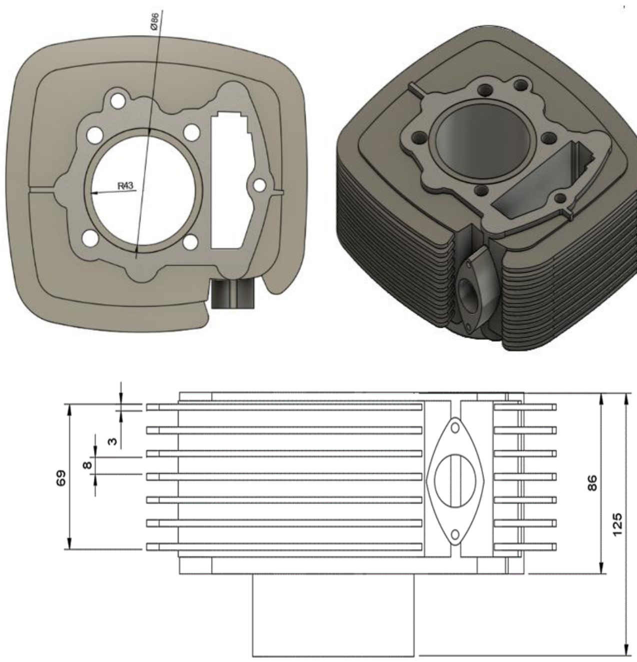


Figure 3. Cylinder Block Design

The results of the cylinder block design drawing were made using Autodesk fusion 360 software with direct measurement references on a motorcycle. After knowing the standard size of the motorcycle cylinder block used, the next step changes the distance between the fins according to predetermined variables, namely 4 mm, 6 mm, 8 mm, 10 mm. Furthermore, from this design, perforations are added to the cylinder block fins with predetermined variables of 2 mm, 3 mm, 4 mm.

The hypotheses in this study are as follows:

1. H0 = there is no effect of variation in fin groove width and material used on heat transfer rate.
2. H1 = here is an effect of variations in fin groove width and material used on the heat transfer rate.

4. RESULTS AND DISCUSSION

Thermal simulation of cylinder block designs that have been made in Autodesk fusion 360 software produces temperature values on the cylinder block. The simulation results show the difference in temperature in the cylinder block produced according to the variation of the distance between the fins, the variation of perforation and the type of material used. The following results are obtained from thermal simulations on Autodesk fusion 360.

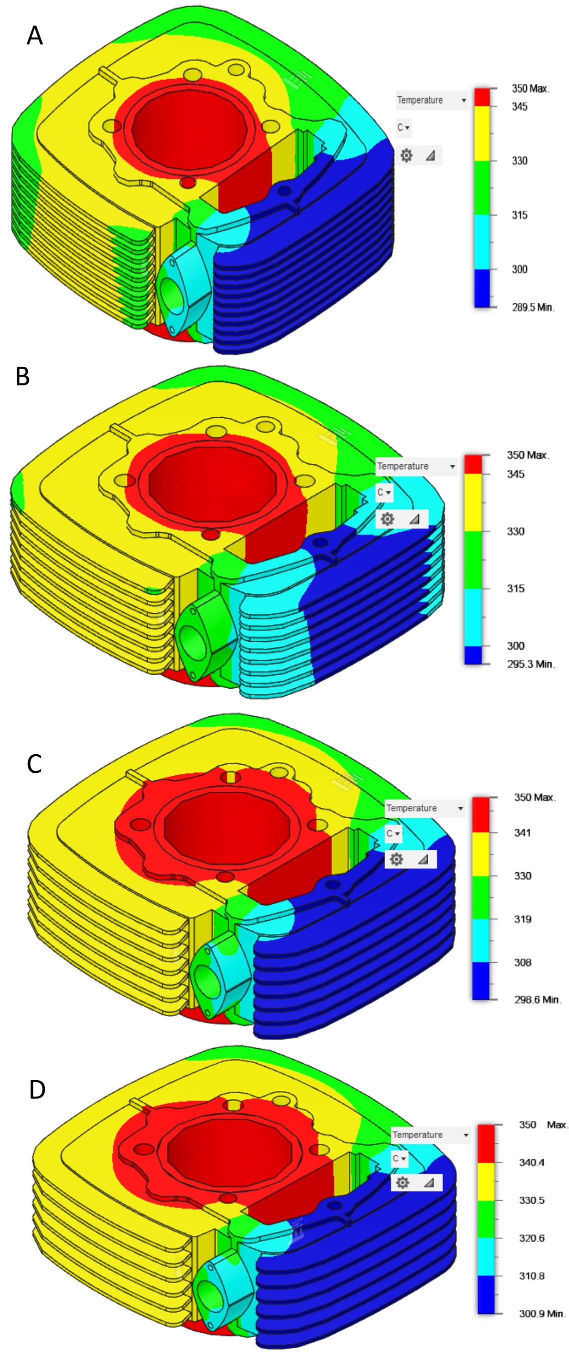
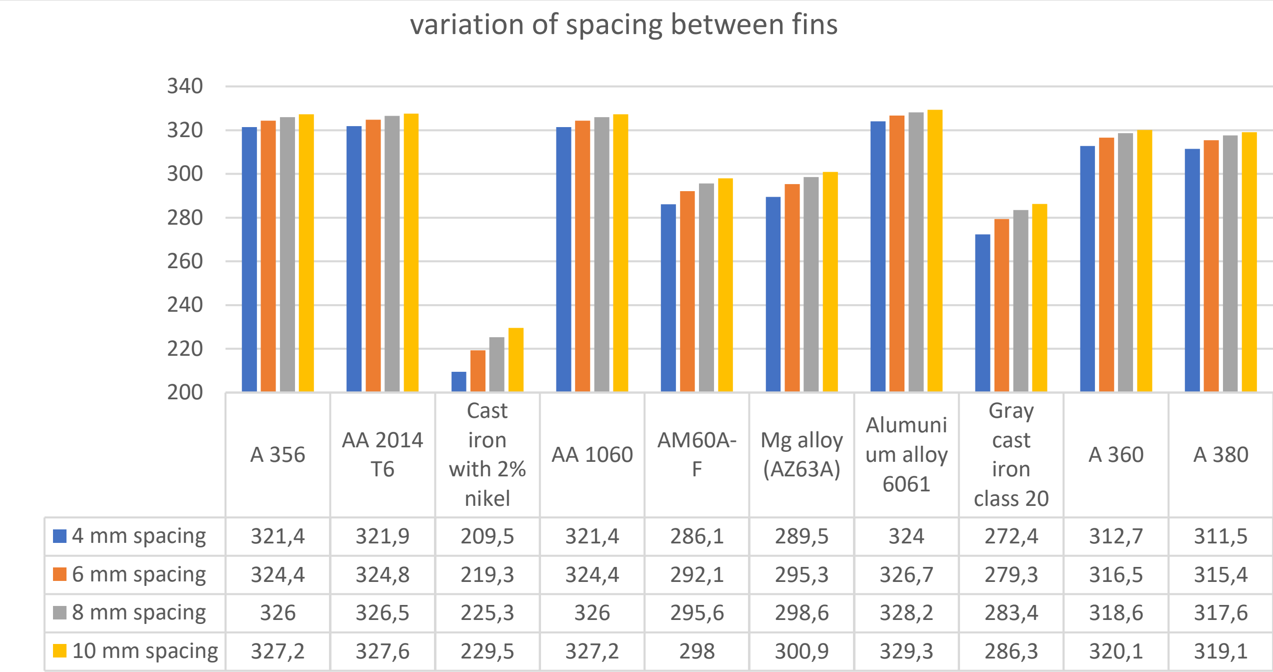


Figure 4. Simulation of the distance between fins 4 mm, 6 mm, 8 mm, 10 mm with Al 356 material

In Figure 4. shows the results of thermal simulations with the distance between the fins in the figure A = 4 mm, B = 6 mm, C = 8 mm, D = 10 mm with AZ63A material, resulting in a heat transfer temperature distribution on the cylinder block fins which initially the input temperature is applied 350 ℃ to the engine cylinder. The heat transfer temperature distribution is 289.5 ℃ for the distance between 4 mm, 295.3 ℃ for the distance between the fins of 6 mm, 295.6 ℃ for the distance between the fins of 8 mm, 298 ℃ for the distance between the fins of 10 mm on the cylinder block fins which are marked in blue in the figure above.



	A 356	AA 2014 T6	Cast iron with 2% nikel	AA 1060	AM60A-F	Mg alloy (AZ63A)	Alumunium alloy 6061	Gray cast iron class 20	A 360	A 380
4 mm spacing	321,4	321,9	209,5	321,4	286,1	289,5	324	272,4	312,7	311,5
6 mm spacing	324,4	324,8	219,3	324,4	292,1	295,3	326,7	279,3	316,5	315,4
8 mm spacing	326	326,5	225,3	326	295,6	298,6	328,2	283,4	318,6	317,6
10 mm spacing	327,2	327,6	229,5	327,2	298	300,9	329,3	286,3	320,1	319,1

Figure 5. Graph of Variation of Distance between Fins

Figure 5 shows the minimum temperature heat transfer distribution graph achieved in the cylinder block with variations in the distance between fins. The highest graph is shown by the 6061 Aluminum material type with the highest minimum temperature heat transfer value achieved at a distance between fins of 10 mm higher than all material types and variations in the distance between fins used in this study. The lowest graph is shown by the material type Cast iron with 2% nickel with the lowest achieved minimum temperature heat transfer value at a distance between fins of 4 mm lower than all material types and variations in the distance between fins used in this study. The temperature decreases with a decrease in the distance between the fins for an applied thermal load of 350 °C or in other words, the heat transfer rate increases slightly with a decrease in the distance between the fins. Although the magnitude of the minimum temperature drop is minimal between the different fin spacings, it can be seen that the temperature drop or heat transfer rate increase is consistent with all materials as the fin spacing varies. As the fin spacing increases, the fins available for heat transfer to occur at the fins decrease and less turbulence is created so that the minimum temperature achieved is greater than the temperature achieved at smaller fin spacing.

The heat generated during combustion is transferred by convection to the ambient air, the greater the convection Q value the faster the convection heat dissipation generated. By increasing the diameter of the perforation can expand the convection release area so as to accelerate the heat dissipation that occurs. While the effect of material type on the temperature value is caused by the thermal conductivity value of each material. Thermal conductivity of the material is a quantity that states the ability of a material to conduct heat. The relationship between the thermal conductivity value of the material with the ability to conduct heat is proportional. This means that the greater the conductivity, the greater the ability to conduct heat as well so that the release of heat that occurs will be faster.

Analysis Anova
Factor Information

Factor	Type	Levels	Values
Material	Fixed	10	A 356; A 360; A 380; AA 1060; AA 2014T6; Aluminum 6061; AM60A-F; cast iron with 2% nikel; Grey cast Iron class 20; Magnesium alloy (AZ63A)
Distance Between Fins	Fixed	4	4; 6; 8; 10

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Material	9	39115,5	4346,16	1005,70	0,000
Distance Between Fins	3	507,6	169,20	39,15	0,000
Error	27	116,7	4,32		
Total	39	39739,8			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2,07883	99,71%	99,58%	99,36%

Based on the anova table above, it is known that the p-value affects the data analysis, with the hypothesis method to get a conclusion from the table above about how much influence the material variation, the distance between fins and the diameter of the perforation has on the min_temp heat transfer based on the p-value.

Hypothesis of the effect of material variation and spacing between fins on min_temp heat transfer. The explanation of this research hypothesis is as follows:

1. Null Hypothesis ($H0$)
   There is no effect of variation in fin groove width, perforation diameter and material used on heat transfer rate.
   Alternative Hypothesis ($H1$)
   There is an effect of variations in fin groove width, perforation diameter and material used on the heat transfer rate.
2. Significant level alpha (a) = 0.05
3. H1 is accepted if p-value < alpha (a) = 0.05
   H1 is rejected if the p-value > alpha (a) = 0.05

Calculation of hypothesis decision making based on the data in the anova table above. If p-value < probability value (a) = 0.05, then H1 is accepted and H0 is rejected, if p-value > probability value (a) = 0.05, then H1 is rejected and H0 is accepted. Material p-value data = 0.000, then H1 is accepted and H0 is rejected, meaning that there is a significant difference in the variation of material types on the resulting min_temp heat transfer value. While the data p-value of the distance between fins = 0.000, then H1 is accepted and H0 is rejected, meaning that there is a significant difference in each variation of the distance between fins on the resulting min_temp heat transfer value.

5. CONCLUSIONS

Based on the results of the research analysis, the following conclusions can be drawn:

1) Heat transfer increases slightly with decreasing fin spacing. Although the magnitude of the decrease in minimum temperature is very minimum between different fin spacings, it is seen that the decrease in temperature or increase in heat transfer rate is consistent with all materials in the presence of variation in fin spacing. As the fin spacing increases, the fins available for heat transfer to occur at the fins decrease and less turbulence is created so that the minimum temperature achieved is greater than the temperature achieved at smaller fin spacing.
2) The effect of material type on temperature value is caused by the thermal conductivity value of each material. This means that the greater the conductivity, the greater the ability to conduct heat so that the release of heat that occurs will be faster. The lowest heat transfer temperature occurs in cast iron material with 2% nickel, while the highest heat transfer temperature occurs in 6061 aluminum material.

6. ACKNOWLEDGMENTS

Thank you to Polinema Mechanical Engineering Department for supporting this journal.

7. CONTRIBUTIONS

- Drafting and writing: Sugeng Hadi Susilo, Mohamad Zainal Abidin
- Writing Systematics: Sugeng hadi susilo.
- Image Design: Mohamad Zainal Abidin
- Simulation: Mohamad Zainal Abidin
- Methodology: Mohamad Zainal Abidin, Sugeng Hadi Susilo
- Analysis: Mohamad Zainal Abidin, Sugeng Hadi Susilo

8. REFERENCES

[1] Kummitha, O. R., & Reddy, B. V. R. (2017). Thermal Analysis of cylinder block with fins for different materials using ANSYS. Materials today: proceedings, 4(8), 8142-8148..

[2] Ibrahim, T. K., Mohammed, M. N., Mohammed, M. K., Najafi, G., Sidik, N. A. C., Basrawi, F., ... & Hoseini, S. S. (2018). Experimental study on the effect of perforations shapes on vertical heated fins performance under forced convection heat transfer. International Journal of Heat and Mass Transfer, 118, 832-846..

[3] Chaitanya, P. S., Rani, B. S., & Kumar, K. V. (2014). Thermal analysis of engine cylinder fin by varying its geometry and material. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 11(6), 37-44.

[4] Dubey, D., Singh, D., & Thakur, H. (2017). Thermal Analysis of Engine Cylinder having thick tip fin with varying slot sizes and material. Materials Today: Proceedings, 4(8), 7636-7642.

[5] Ehteshum, M., Ali, M., Islam, M. Q., & Tabassum, M. (2015). Thermal and hydraulic performance analysis of rectangular fin arrays with perforation size and number. Procedia Engineering, 105, 184-191.

[6] Ibrahim, T. K., Mohammed, M. N., Mohammed, M. K., Najafi, G., Sidik, N. A. C., Basrawi, F., ... & Hoseini, S. S. (2018). Experimental study on the effect of perforations shapes on vertical heated fins performance under forced convection heat transfer. International Journal of Heat and Mass Transfer, 118, 832-846.

[7] Jatnika, D., & Mudasir, H. (2021). Analisis dampak perubahan volume silinder sepeda motor 110 cc terhadap kinerja. Jurnal Online Sekolah Tinggi Teknologi Mandala, 16(1), 65-76.

[8] Yunus, M. (2019). Analysis of Cylinder Block Ability to Piston Friction on Suzuki Shogun 125 Motorcycle Year 2014 at Yelhana Motor Workshop. Teknika Sains: Journal of Engineering Science,4(2), 37-44.

[9] Martua Manik, I. C. (2022). Sifat Mekanis Paduan Aluminium A356 dengan Penambahan Unsur Tembaga Hasil Proses Gravity Casting. JTERA (Jurnal Teknologi Rekayasa), 201-208.

[10] Ugender, S., Kumar, A., & Reddy, A. S. (2014). Experimental investigation of tool geometry on mechanical properties of friction stir welding of AA 2014 aluminium alloy. Procedia Materials Science, 5, 824-831.

[11] Naief, T. M., & Rashid, K. H. (2016). Comparative Study for Anodizing Aluminum Alloy 1060 by Different Types of Electrolytes Solutions. In First Scientific Conference on Modern Technologies in Oil & Gas Refining (Vol. 1, pp. 10-16).

[12] He, A., & Zeng, J. (2017). Direct preparation of low Ni-Cr alloy cast iron from red mud and laterite nickel ore. Materials & Design, 115, 433-440.

[13] Khokhlova, J., Khokhlov, M., & Synyuk, V. (2016). Magnesium alloy AZ63A reinforcement by alloying with gallium and using high-disperse ZrO2 particles. Journal of Magnesium and Alloys, 4(4), 265-269.

[14] Leon, J. S., & Jayakumar, V. (2014). Investigation of mechanical properties of aluminium 6061 alloy friction stir welding. International Journal of Students' Research in Technology & Management, 2(04), 140-144.

[15] Sheladiya, M. V., Acharya, S. G., & Acharya, G. D. (2022). Effect of microstructure on the hardness of ASTM A48 class 20 flaked

graphite cast iron. International Journal of Cast Metals Research, 35(4), 73-83.

[16] Sathishkumar, S., Kannan, S., & ThirumalaiKumar, S. (2017). Material Behaviour of Aluminum Al 360 Alloy Hollow Ring Preforms. Journal of Mechanical Engineering Research and Developments, 40, 595-610.

[17] Obiekea, K. N., Aku, S. Y., & Yawas, D. S. (2014). Effects of pressure on the mechanical properties and microstructure of die cast aluminum A380 alloy. Journal of minerals and materials characterization and engineering, 2(03), 248.

[18] Umurani, K., Nasution, A. R., & Irwansyah, D. (2021). Heat Transfer and Pressure Drop in a Quadrilateral Channel with 90 Degree V Ribs. Journal of Materials Engineering, Manufacturing and Energy, 4(1), 37-46.

[19] Sathishkumar, S., Kannan, S., & ThirumalaiKumar, S. (2017). Material Behaviour of Aluminum Al 360 Alloy Hollow Ring Preforms. Journal of Mechanical Engineering Research and Developments, 40, 595-610.

[20] Faizal, A., Wahyudi, S., & Gapsari, F. (2021, June). Analysis of Heat Transfer and Performance on Motorcycle Engine Fins by Varying Air Velocity. In SENASTER "National Seminar on Applied Technology Research" (Vol. 2, No. 1).