Simulation on the Effect of Braking Force and Brake Shoe Material Type on The Wear Rate of Railway Bogie Brake Block

by Hersendro Sulistyo

Submission date: 07-Sep-2024 10:49AM (UTC+0700)
Submission ID: 2447108088
File name: Jurnal_Skripsi_TYO_Inggris_CEK.docx (7.29M)
Word count: 3833
Character count: 18981

Simulation on the Effect of Braking Force and Brake Shoe Material Type on The Wear Rate of Railway Bogie Brake Block

Hersendro Sulistyo [1], Vinan Viyus [2*]

[1,2] Department of Mechanical Engineering, State Polytechnic of Malang, Indonesia.
E-mail: vinanviyus@mail.com *
* Corresponding Author

ABSTRACT | ARTICLE INFO

The brake block in the railway bogie system is an important component in supporting the operational safety of trains, so it needs to be inspected to determine its performance and service life. A simulation-based study was conducted to predict the wear rate of railway brake block with oriented braking force (F = 25.66 kN - 29.54 kN) and different material types, namely grey cast iron with hardness 170 HBN and metallic composite with hardness 90 HRR. The method of the study was carried out by Finite Element Analysis (FEA) simulation and calculating the wear rate with the Archard wear equation to measure the comparison of the amount of wear volume that occurs on the two materials. The results of the braking ability calculation can be concluded that the different types of brake block materials can affect the ability to decelerate during the deceleration process, causing differences in stopping mileage according to the type of material, such as gray cast iron (μ = 0.30) which has an average mileage of 15 metres and metallic composite (μ = 0.21) has an average mileage of 66 metres. The wear simulation results obtained are that the grey cast iron brake block has an average wear rate of 2,8285e-08 mm^3/s which is greater than the metallic composite which is only 1,5391e-08 mm^3/s. With this data, it can be concluded that oriented to the braking force load, the metallic composite brake block material has the advantage of a longer service life than grey cast iron.

Article history
Received
Revised
Accepted

Keywords
Archard
Brake Block
Finite Element Analysis

a.

1. Introduction

The braking system is a crucial part for every means of transport that functions as a medium to control speed while moving [1]. In land transportation, braking components are generally used on wheels, discs, or shafts that are connected to the vehicle's motion system, so that the driver can use it to control the speed of the vehicle by reducing the speed as desired or stopping it [2]. In the use of braking systems, the selection of material types and brake models will adjust to the needs that refer to the specifications of the facilities that use them because various types of brakes have different functions and capabilities [3].

Trains are mass transportation vehicles that play a role in transferring logistics and as a medium for mobilising people to travel between regions [4]. Trains have large carrying capacity and heavy loads so that support is needed in a good braking system so that they can operate safely and do not cause fatality [5]. It is known that the braking system is a critical part that needs more attention to minimise the risks that may occur [1]. Regarding this, a research action was carried out on the railway brake block lining to measure the brake usage time on the train. The brake usage time in this study can be reviewed by knowing the brake wear rate of the two different types of materials and then a comparison is made to determine the difference in wear rates.

It is known that the braking system needs to be arranged in such a way as to avoid excessive wear on the surface of the brake lining so as to make its use life shorter than it should be [6]. This will cause economic losses in terms of usage because it requires the replacement of components in a shorter time span. In relation to the rate of brake wear, the selection of the right material for the brake lining is an important factor because it will affect the behaviour and strength in resisting the penetration of brake pressure effects comprehensively. In addition to the material, there is another factor, namely the amount of force involved in providing a load can potentially cause brake lining wear because friction and compressive forces will trigger penetration that causes adhesive wear.

A simulation-based research is conducted to analyse the wear of brake block linings with material specifications and dimensions that will be adjusted to actual use. This simulation will be carried out using Computer Aided Engineering (CAE) simulation which has the ability to analyse structure, dynamics, and product optimisation. This wear simulation will use Archard Wear Extension and volume loss due to wear to obtain the amount of volume worn in a certain time interval so that the wear rate can be known. With this research, the results obtained can be used as a comparison between the two types of brake block materials, namely grey cast iron and metallic composites. Simulations were conducted to compare the wear rate of the two brake block materials and their ability to decelerate trains. With this research, the results are expected to be a reference for the prediction of brake block wear of both materials to determine the quality of each material and the ideal maintenance time range that should be carried out based on the occurrence of wear, as well as a good maintenance time interval so as to minimise the failure of the braking system.

2. Method

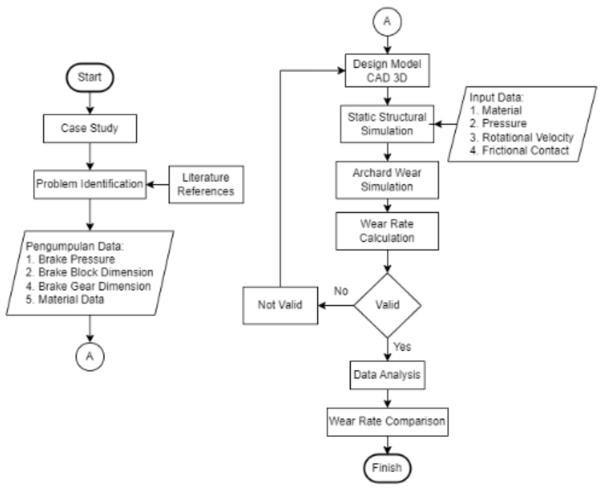

Fig. 1. Research flowchart

Research on brake block lining is carried out by simulation testing methods on brake block elements. The testing process uses computer-based structural analysis software (Computer Aided Engineering) with the Finite Element Analysis (FEA) method to get an overview and wear prediction parameters from the simulation results of the brake block behaviour when braking. The modelling stage is carried out using CATIA V5 software to create a bogie wheel design and brake block that will be simulated. Then the simulation stage in ANSYS R2 software is divided into two stages of the process, namely static structure to provide force loading, pressure, rotational speed and boundary on the model to input the appropriate variable parameter numbers. then to analyse the amount of wear on the model using wear simulation (Archard method) to determine the amount of wear volume and wear rate that occurs on each brake block specimen.

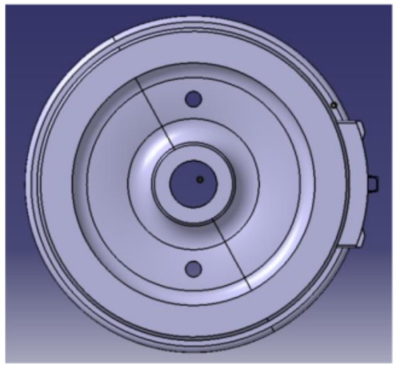

Fig. 2. CAD design of brake block

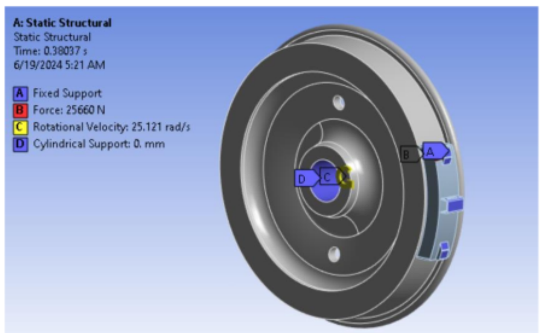

Fig. 3. Static analysis of brake block

In the static analysis tool, the following data will be inputted:

1. Material
2. Pressure
3. Rotational Velocity
4. Frictional Contact
5. Fixed Support
6. Cylindrical Support

2.1. Material

The materials used for wear simulation are Gray Cast Iron and Metallic Composite Brake T360 whose specifications can be seen in table 1.

Table 1. Material properties [2] ; [7]

Property	Material	
	Gray Cast Iron	Metallic Composte

Density (kg/m^3)	7200	2670
Ultimate Strength (MPa)	250	240
Tensile Strength (MPa)	0	0
Heat Cosntant Pressure (J/kg. °C)	447	447
Thermal Conductivity	18.9	1,32
Modulus of Elasticity (Pa)	2e+11	2e+11
Poisson's ratio	0.30	0.30
Hardness	170 HBN	90 HRR

2.2 Brake Thrust Force

Air braking on trains is a braking system that uses compressed air to control the speed and stop the train. The air brake system consists of an air compressor, storage tank, distribution pipes, and brake cylinders installed on each train carriage. The pressure value will affect the thrust force that occurs. To find out the normal force of the brake block, it can be reviewed by knowing the thrust force of the air brake first [4]. The calculation is as follows:

$$F = (A \times P) - f_p$$

Description:

F = Thrust Force (N)
A = Area (m^2)
P = Pressure (N/m^2)
f_p = Spring Force (N)

2.2. Wear Rate

It is known that wear can be defined as damage to the surface of solids on an element of the object due to a certain friction or penetration [8]. In the process of wear, it generally involves a process of progressive erosion of the material caused by friction between solid surfaces that are in contact with each other due to pressure. Technically, wear itself is not a basic property of the material, but rather a response caused by the material to touch disturbances from external systems (contact between surfaces with other objects).

The calculation of wear itself also has various methods, including the Archard method which was discovered in 1953 by experimental methods. The occurrence of material wear on the brakes is a factor that makes the brake lining lose its performance in producing friction on the wheels of the vehicle so that until a certain time it needs to be replaced to support operational safety. The assessment of wear can be done by calculating the wear rate on the brake lining components in contact with the wheel to calculate the amount of wear. The equation form of the Archard wear model to calculate the wear volume is as follows:

$$V = \frac{k\,F\,S}{H}$$

Description:

V = Wear volume (mm^3)
k = Wear coeffient
F = Contact force (N)
S = Sliding distance (mm)
H = Material Hardness (MPa)

The equation form of the Archard derivative of time can be used to calculate the wear rate, which is as follows:

$$\dot{W} = \frac{k\ F\ v}{H}$$

Description:

$\dot{W}$	= Wear velocity (mm^3/s)
k	= Wear coefficient
F_N	= Contact force (N)
v	= *Sliding velocity relative* (mm/s)
H	= Hardness (MPa)

2.3. Kinematics and Dynamics

Identification of moving objects can be divided into two related things, namely kinematics and dynamics [9]. Kinematics is a scientific basis in the movement of objects without calculating the cause of the object to move, while dynamics reviews things that are factors that cause an object to move [9]. In dynamics, the cause of acceleration or deceleration in a system of objects is also reviewed. The following is the calculation equation:

Dynamics Equation:

$\sum F$ = m a (Newton's law II)

Description:

F	= Force (N)
m	= Mass (kg)
a	= Acceleration (m/s^2)

Kinematics Equation:

$V^2 = V_0^2 \pm$ a S (Non-constant linear velocity)

Description:

V	= Final speed (m/s)
V_0	= First speed (m/s)
a	= Acceleration (m/s^2)
S	= Distance (m)

3. Results and Discussion

3.1 Braking Force

Table 2. Thrust force

Pressure (N/m^2)	Cylinder Brake Area (m^2)	Thrust Force (N)
350.000	0,07065	24.727,50
355.000	0,07065	25.080,75
360.000	0,07065	25.434,00
365.000	0,07065	25.787,25
370.000	0,07065	26.140,50
375.000	0,07065	26.493,75
380.000	0,07065	26.847,00
385.000	0,07065	27.200,25
390.000	0,07065	27.553,50

395.000	0,07065	27.906,75
400.000	0,07065	28.260,00

With the data from the calculation of brake pressure acting on the brake cylinder, it is known that the amount of braking force that works as thrust is in the range of 24,727.50 N - 28,260 N. The force from the brake cylinder is transferred to the brake block through the brake lever and brake gear on the train underframe. The lever on the brake gear has a moment value that can change the output of the thrust force coming out of the wind brake piston. The calculation of the braking force acting on the brake block is as follows:

Table 3. Braking force

Thrust Force (N)	Moment	Braking Force (N)
24.727,50	1,1	25.660,250
25.080,75	1,1	26.048,825
25.434,00	1,1	26.437,400
25.787,25	1,1	26.825,975
26.140,50	1,1	27.214,550
26.493,75	1,1	27.603,125
26.847,00	1,1	27.991,700
27.200,25	1,1	28.380,275
27.553,50	1,1	28.768,850
27.906,75	1,1	29.157,425
28.260,00	1,1	29.546,000

In table 2 and table 3, it can be seen that the braking force works effectively in the range of 25.6 kN - 29.5 kN at a cylinder brake pressure of 3.5 bar - 4 bar). The moment of the working braking arm makes the force increase by 10% when it reaches the brake block.

3.2 Simulation Result

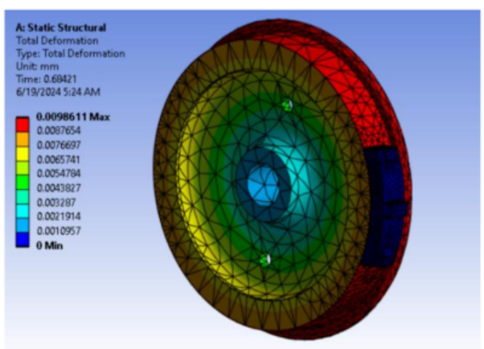

Fig. 4. Static finite element analysis

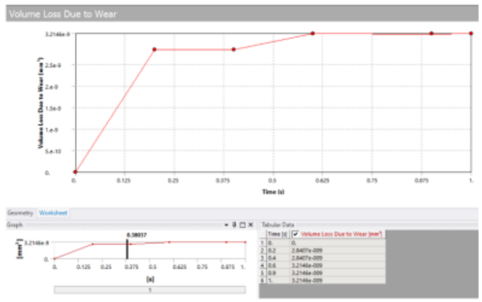

Fig. 5. Archard wear simulation

The results of the simulation in fig. 4. and fig. 5. which is carried out for 1 second on the brake lining proves that the amount of force that occurs can cause a reduction in the volume of the brake block or the volume that is worn. In units of volume, the results are then divided by the time of wear on the brake block to find out how fast the wear process occurs in grey cast iron and metallic composite brake blocks.

3.1. Braking Capability

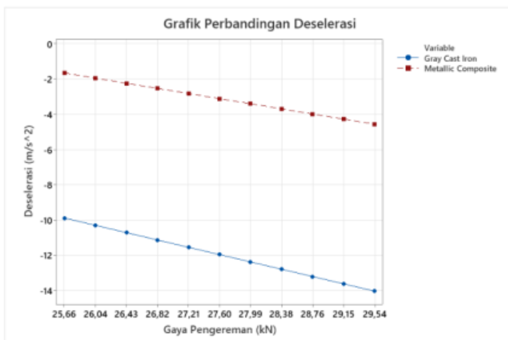

Fig. 6. Deseleration comparison

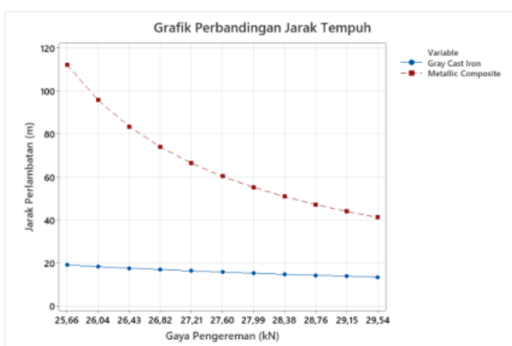

Fig. 7. Braking distance comparison

Based on the comparison results in fig. 6. and fig. 7. it can be seen that in dry friction contact conditions between bogie wheels and rails will experience differences in mileage depending on the coefficient of friction. The grey cast iron (μ = 0.30) is able to stop with an average distance of 15 metres. The grey cast iron brake block can decelerate with a faster time and shorter distance than the metallic composite ($\mu = 0.21$) whose average distance reaches 66 metres. Therefore, based on the chart review data, it can be stated that grey cast iron is still classified as more reliable than metallic composite in braking ability. If using the approach of the archard wear volume equation in sub-chapter 2.3 which shows that the mileage affects wear.

3.2. Wear Calculation

Table 4. Wear volume

Material	Braking Force (N)	Wear volume at time (mm^3) 0	0.2	0.4	0.7	1	Average wear volume (mm^3)
Gray Cast Iron	25660.250	0	0	0	5.6193E-10	8.3613E-09	2.8285E-08
	26048.825	0	0	0	5.7860E-10	8.2257E-09	
	26437.400	0	0	0	0	6.3825E-09	
	26825.975	0	0	0	0	6.7852E-09	
	27214.550	0	0	0	0	4.0009E-08	
	27603.125	0	0	0	0	7.0712E-09	
	27991.700	0	0	0	1.4141E-09	2.1717E-08	
	28380.275	0	0	0	1.7692E-09	1.6882E-08	
	28768.850	0	9.1212E-08	9.3923E-08	9.5745E-08	9.5745E-08	
	29157.425	0	0	0	0	4.9674E-09	
	29546.000	0	9.0534E-08	9.3263E-08	9.4987E-08	9.4987E-08	
Metallic Composite	25660.250	0	0	0	2.4388E-10	3.5699E-09	1.5391E-08
	26048.825	0	0	0	3.9878E-10	3.6682E-09	
	26437.400	0	0	0	0	7.3663E-09	
	26825.975	0	0	0	4.0613E-10	2.2235E-08	
	27214.550	0	0	0	0	3.9023E-09	
	27603.125	0	0	0	0	2.0168E-09	
	27991.700	0	0	0	0	1.7919E-09	
	28380.275	0	0	0	0	2.8851E-09	
	28768.850	0	3.8846E-08	3.9992E-08	4.0763E-08	4.0763E-08	
	29157.425	0	3.8750E-08	3.9899E-08	4.0656E-08	4.0656E-08	
	29546.000	0	3.8557E-08	3.9711E-08	4.0441E-08	4.0441E-08	

The wear simulation data above, obtained the amount of wear volume that occurs on the brake block in 1 second. By deriving the Archard wear volume equation, the wear rate equation is obtained in units of (mm^3/s). Then the wear rate results are as follows:

Table 5. Wear rate

Testing Step	Braking Force (N)	Wear velocity (mm^3/s) (10^{-8}) *Gray Cast Iron*	*Metallic Composite*
1	25.660,250	0,83613	0,35699
2	26.048,825	0,82257	0,36682
3	26.437,400	0,63825	0,73663
4	26.825,975	0,67852	2,2235

5	27.214,550	4,0009	0,39023
6	27.603,125	0,70712	0,20168
7	27.991,700	2,1717	0,17919
8	28.380,275	1,6882	0,28851
9	28.768,850	9,5745	4,0763
10	29.157,425	0,49674	4,0656
11	29.546,000	9,4987	4,0441
Mean value		2,8285	1,5391

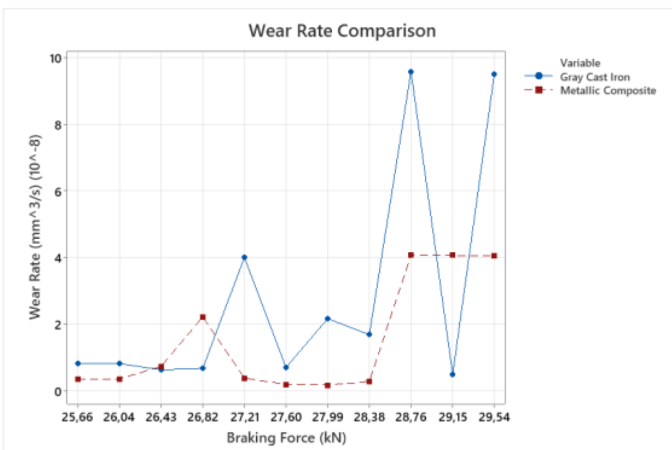

Fig. 8. Wear rate comparison

With the following data, it can be seen that the wear rate that occurs in grey cast iron (H = 170 HBN) will be greater than the metallic composite (H = 90 HRR) which makes the life of the grey cast iron brake block shorter because with the same force value, the average wear that occurs is greater.

3.3. Analisis Data Statistik

Statistical analysis is used as a reference to determine the effect of independent variables and dependent variables statistically. The following is processing with design of experiment (DOE) factorial.

Table 6. Analysis of variance

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	66.384	22.128	4.30	0.019
Linear	2	62.337	31.168	6.05	0.010
Material	1	9.145	9.145	1.78	0.199
Braking Force (N)	1	53.192	53.192	10.33	0.005
2-Way Interactions	1	4.047	4.047	0.79	0.387
Material*Braking Force (N)	1	4.047	4.047	0.79	0.387
Error	18	92.719	5.151		
Total	21	159.103			

Based on the data referring to the statistical analysis of variance table, it is known that although braking force and material type affect the amount of wear rate that occurs, the statistical results may be able to distinguish the two compositionally, as well as the dominant level of influence. The analysis of variance table will help to determine the statistical results of the research conducted. In this study, the level of significance determined was with an a (alpha) value of 5% or 0.05. This is the amount of error that can be accepted in this study, which means that with a high level of confidence, there is no percentage error above this value. In each variable, each P-value is known with the table. In the type of material, the P-value is 0.199 ($P > 0.05$), so the alternative hypothesis (H1) which states that there is a significant effect on the variation of material type is still weak enough to be accepted. While in the value of braking force the P-value is 0.005 ($P < 0.05$), then the null hypothesis (H0) is not enough to be accepted, so the alternative hypothesis (H1) which states that braking force has a significant effect on the wear rate can be accepted.

Table 7. Model Summary

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.26959	41.72%	32.01%	7.85%

Based on the summary module table above, it can be seen that the R-Square (R-Sq) value in this study is 41.72%. This figure is a statistical prediction to describe the effect of the independent variable on the dependent variable. So it can be concluded that braking force and material type have an influence on the size of the brake block wear rate.

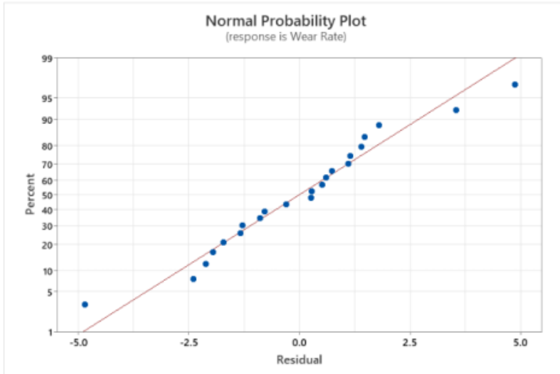

Fig. 9. Normal probability plot

Based on the main effect plot graph, the influence of variables is reviewed specifically on each independent variable separately. In the material factor, the highest wear was obtained in the grey cast iron material. There is a difference between the two materials so that the graph displays a line with a certain slope on the effect line. In the main effect of braking force, there is a significant increase in wear rate from the force range of 25,660.25 N to 29,546 N. The highest wear rate obtained at the force value (F = 29.54 kN) with the slope of the effect line on the braking force looks more significant than the material type variation, which proves that the influence of the wear rate due to the braking force is more dominant than the material itself. These results are in line with Archard wear theory where braking force affects the increase in wear volume and wear rate that occurs in a material.

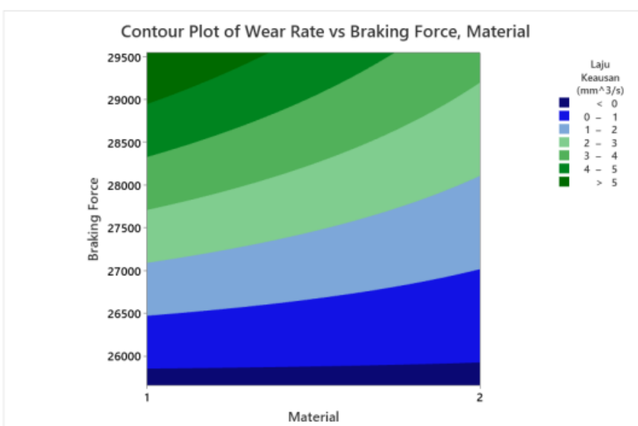

Fig. 10. Contour plot graph

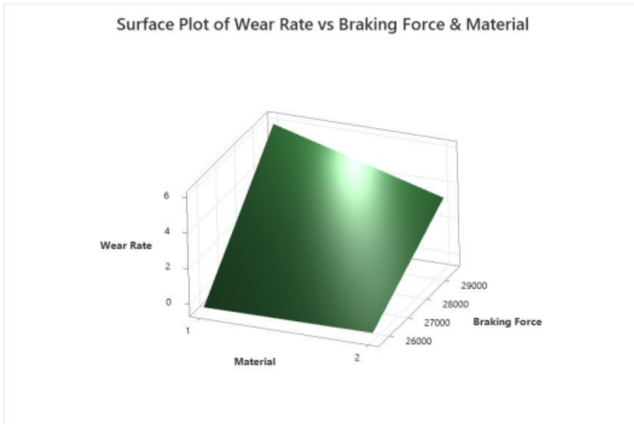

Fig. 11. Surface plot graph

An overview of the 2-way interaction of the independent variable on the dependent variable will be better displayed on the surface plot graph. In this graph, a 3-dimensional picture of the interaction will be obtained so that it can visualise the wear rate results even better. With the above graph, it can be seen that the code (1) is for grey cast iron material and (2) for metallic composite. The results can be seen in the variation of grey cast iron material and 29,546 N force produced the highest wear rate of 9,49 x 10^{-8} mm^3/s. While the smallest is in the metallic composite material with a force of 25,660.25 N at 3,56 x 10^{-9} mm^3/s.

4. Conclusion

- The braking force that occurs in the brake block works in the range of 25,660.250 N to 29,546 N with a cylinder brake pressure of (3.5 - 4 bar). The amount of braking force has an effect in increasing the wear rate that occurs with an increase in wear rate from 8.36 x 10^(-9) to 9.49 x 10^(-8) on gray cast iron material and an increase from 3.56 x 10^(-9) to 4.04 x 10^(-8) on metallic composite material. Based on the statistical test results, the P-value of 0.005 was obtained for the braking force, which is a strong enough reason to reject the null hypothesis (H0) and accept the alternative hypothesis (H1) where there is a significant influence between the amount of braking force and the increase in brake block wear rate.
- The type of brake block material can affect the results of the wear rate that occurs due to the applied force loading. Based on the results of the study, it can be seen that the greater the level of hardness of the brake block material, the more resistant it will be to wear penetration. The highest wear rate is obtained in grey cast iron material at force (F = 29,546 N), and the lowest in metallic composite material at force (F = 25,660.25 N). Thus it is known that the composite material is more resistant to wear. Based on the statistical main effect plot graph, it can be seen that the wear effect caused by braking force is more dominant than the variation of material type.
- Based on the interaction of the combined variables of braking force and material type, it has a comprehensive effect on the wear volume and wear rate of the brake block lining specimens. The different values of friction coefficient (μ) in brake block materials also affect the deceleration ability and the amount of wear volume that occurs. Where the grey cast iron brake block material (μ = 0.30) has a greater deceleration ability so that the travel distance for deceleration is shorter than the metallic composite (μ = 0.21). The volume of wear that occurs on grey cast iron is also greater because friction occurs more roughly and the hardness is smaller than the metallic composite.

Acknowledgment

Previously, the author would like to express his deepest gratitude to all parties who helped and were involved directly or indirectly in this research. The author would like to thank PT X for providing a place and all resources for supporting data in this research. And the author also thanked the mechanical engineering department for providing direction and guidance during the process of this research.

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