Jurnal Rekayasa Mesin
p-ISSN: 1411-6863, e-ISSN: 2540-7678
Vol. 17, No. 1, April **2022**, hal. 151-160

Wear Rate Analysis Due to Dry Sliding Contact of Modified Rail to Increase Life Time in Air Blow Machine

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Diterima: 20-04-2022; Direvisi: 27-04-2021; Dipublikasi: 30-04-2022

Abstrak

Penyemprotan udara bertekanan merupakan cara yang efisien untuk menghilangkan kotoran dan kontaminan lain pada produk setelah proses pemesinan. Penelitian ini membahas sebuah kasus pada industri manufaktur komponen elektrik kendaraan bermotor. Industri tersebut memproduksi pompa bahan bakar dan salah satu komponen pompa tersebut adalah *cover outlet*. Proses akhir *cover outlet* tersebut adalah penyemprotan udara bertekanan melalui *air blow machine* dimana produk meluncur di atas rail. Proses penyemprotan udara bertekanan menjadi terhambat ketika produk *cover outlet* mengalami kemacetan ketika meluncur di atas *rail*. Macetnya produk *cover outlet* tersebut disebabkan karena kontak *dry sliding* antara *rail* dengan produk *cover outlet*. Kontak *dry sliding* menyebabkan keausan pada *rail* sehingga berpengaruh pada operasional mesin dan berkurangnya umur pakai *rail*. Tujuan penelitian ini adalah untuk mengurangi keusan dan meningkatkan umur pakai *rail*. Metode yang digunakan dalam penelitian ini yaitu pegujian mengggunakan alat uji *pin on disk*. Spesimen pin terbuat dari material *cover outlet*, PPS Ryton R-7-120-BL. Spesimen *rail* menggunakan material *rail* aktual, SUS 304 dan material alternatif SUS 410. Parameter pengujian menggunakan pembebanan 8 gr, kecepatan 151 rpm selama 3 menit untuk satu spesimen pin. Hasil penelitian menunjukkan nilai laju keausan dan laju keausan spesifik menggunakan material alternatif mengalami penurunan 87,7% dari material *rail* aktual. Nilai laju keausan material rail SUS 304 sebesar 0,00486 mm^3/menit dengan laju keausan spesifik 0,0037 mm^3/Nm. Laju keausan material SUS 410 sebesar 0,000593 mm^3/menit dengan laju keausan spesifik 0,000455 mm^3/Nm. Hasil analisis umur pakai pada volume keausan yang diijinkan 498,2 mm^3 menunjukkan peningkatan dengan menggunaan material alternatif. Material aktual SUS 304 bertahan 1.708 jam sedangkan SUS 410 bertahan 14.002 jam.

Kata kunci: keausan; kontak *dry sliding*; *cover outlet*; *air blow machine*; *pin on disk*

Abstract

Air compressed blowing is an efficient way in order to remove dirts and other contaminants from product after machining process. This research discuss a case study in the automotive electrical component manufacturing industry. The industry produces fuel pumps and one of its components is the cover outlet. The final process of the outlet cover is spraying compressed air through an air blow machine where the product slides over the rail. The process of spraying compressed air becomes hampered when the cover outlet product is jammed when sliding on the rail. The jam of the cover outlet product was caused by dry sliding contact between the rail and the cover outlet product. Dry sliding contacts cause wear on the rails which it affects the operation of the machine and reduces the service life of the rails. The purpose of this research is to reduce wear and increase the service life of the rail. The method used in this research is testing using a pin on disk test tool. The pin specimen is made of outlet cover material, PPS Ryton R-7-120-BL. The rail specimens used the actual rail material, SUS 304 and the alternative material SUS 410. The test parameters used a loading of 8 g, a speed of 151 rpm for 3 minutes for one pin specimen. The results showed that the wear rate and specific wear rate using alternative materials decreased by 87.7% from the actual rail material. The wear rate of the SUS 304 rail material is 0.00486 mm^3*/min with a specific wear rate of 0.0037* mm^3*/Nm. The wear rate of SUS 410 material is 0.000593* mm^3*/min with a specific wear rate of 0.000455* mm^3*/Nm. The results of the analysis of the wear life at the allowable wear volume of 498.2* mm^3 *show an increase with the use of alternative materials. The actual material SUS 304 lasts 1,708 hours while the SUS 410 lasts 14,002 hours.*

Keywords: *wear; dry sliding contact; cover outlet; air blow machine; pin on disk*

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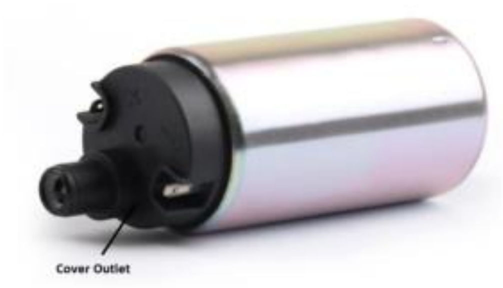
1. Introduction

Air blowing is an efficient way to remove dirt, rust, fluids, and other contaminants from the machining process or piping [1]. This research takes place in an automotive manufacture industry which produce electrical components for vehicle, PT Mitsuba Indonesia. One of the product is fuel pump which an motorized component works to distribute fuel into internal combustion system. Those fuel channelled out through fuel pump component called cover outlet. The cover outlet production finishing step consist of air compressed sparying using air blow machine in order to clean product from cover outlet after machining process. The cover outlet products as shown in Figure 1 (b) passed air blow machine through a modified rail. This process involved contact between cover outlet product and modified rail. The air blow process in PT Mitsuba Indonesia experience obstacle due to wear phenomenon on the modified rail. Wear on the modified rail caused the cover outlet product jammed and hit air blow machine’s stopper in an improper position. Wear occurs due to product sliding during the air blow process which must be carried out in dry conditions without lubrication (dry sliding). Besides having an effect on engine operation, the wear and tear that occurs also affects the service life of the rail. Rail is damaged quickly because wear occurs faster in dry sliding conditions. Figure 1 (a) shows the fuel pump product with cover outlet attached on it.



(a)

(b)

Figure 1. (a) Fuel pump with cover outlet attached and (b) Cover outlet product

Research related to the dry sliding contact phenomenon and wear associated with sliding contact materials has been carried out by many world researchers [1-3]. Wear modelling due to dry sliding contact phenomenon also been conducted with the strong correlation result between the modelled and measured volumetric wear [4]. This paper research take up a significant case study of dry sliding contact occur in manufacture industry. Cover outlet product which slide on top of modified rail where the rail’s wear caused the product to jammed. The jammed product caused an air blowing process to be slow and ineffective. This research aim to analyze wear rate phenomenon occur in air blow machine due to dry sliding contact between rail and cover outlet product. Figure 2 shows the modified rail used in PT Mitsuba Indonesia.

Figure 2. Modified rail

2. Material and Method

Research method consist of 5 steps: (i) Data collection through direct observation in PT Mitsuba Indonesia, data shown in Table 1-3, (ii) Pin on disc experimental preparation, consist of material preparation which are disc specimen made of the actual modified rail material (SUS 304), addition of alternative rail material (SUS 410), pin specimen material made of the actual cover outlet material (PPS Ryton R-7l20BL) and tribotester machine, (iii) Defining the experimental parameter as shown in Table 6, (iv) Conducting the experiment and (v) Experiment data validation using statistics.

2.1. Data collection

This research was conducted through experimental method to determine the wear rate, wear volume and material service life. Table 1 shows the data of material involved in dry sliding contact: modified rail and cover outler product. Data obtained from PT Mitsuba Indonesia.

Table 1. Material involved in dry sliding contact data

Part	Material	Material Density (gr/mm^3)
Modified rail	SUS 304	0.008
Cover Outlet	PPS Ryton R-7-l20BL	0.00199

Table 2 denoted the modified rail and cover outlet physical specification data obtained from direct observation in PT Mitsuba Indonesia. The actual wear occur on the rail measured using vernier caliper. Data shown from two direct observation on wear occur in the rail, both exceed the allowed wer limit.

Table 2. Modified rail and cover outlet spacification data

Rail Specification	
Profile	Round bar shaft
Dimension	Diameter : 4 mm
	Length : 550 mm
Allowed wear limit	0.5 mm
Actual wear occur	0.6 mm for 2184 hours usage (measured at 21 Febuary 2018)
	0.175 mm for 2688 hours usage (measured at 25 July 2018)
Cover Outlet Specification	
Mass	11.66 gr

Table 3 represent the production parameter condition of air blow machine in PT Mitsuba Indonesia. Those data derived from direct field observation.

Table 3. Production parameter data

Parameter	
Modified rail slope	15.5 degree
Sliding time	4 s
Sliding distance	550 mm
Contact specification	Dry sliding
Temperature	Room temperature (25^{0}C)
Operational time	24 hour

2.2. Pin on disc experimental preparation

The experimental method used in this research is pin on disc method. The experimental specimens consist of 3 materials, two disc materials and one pin material. The disc specimens made of two material, the actual modified rail material (SUS 304) and the alternative material (SUS 410). Table 4 shows the disc specimen properties. Disc specimen hardness value denoted in HRB scale. Pin specimen made with the actual cover outlet material, PPS Ryton R-7-l20BL. Table 5 shows the mechanical properties of pin specimen. The hardness value of the pin material is assumed to be the same as the hardness of the actual product material specifications for the cover outlet on the Shore D scale. Pin on disc experiment is conducted using a tribotester machines illustrated in Figure 3.

Table 4. Disc specimen properties

Properties	Disc 1	Disc 2
Material	SUS 304	SUS 410
Quantiity (pcs)	1	1
Dimension (mm)	Ø70 x 4	Ø70 x 4
Initial mass (gr)	121.099	116.0067
Hardness, reference (BHN) [5]	150-190	190-320
Hardness, reference (HRB) [5]	78.9-89.7	89.7-114
Hardness, tested (HRB)	88	100.3
Density (gr/mm^3)	0.008	0.0078

Table 5. Pin specimen properties

Properties	Pin
Material	PPS Ryton R-7-l20BL
Hardness (Shore D) [6]	88
Quantity (pcs)	60
Radius (mm)	5
Length (mm)	27
Average mass (gr)	3.4

Figure 3. Pin on disc experiment kit

2.3. Defining the experimental parameter

Figure 4 illustrated the dry sliding phenomenon of modified rail and cover outlet product. An object slide on inclined plane assumed to be the dry sliding phenomenon happened in this air blow machine case. The inclined plane slope (θ), sliding distance (Δd) and sliding time (Δt) parameters value are obtained from the real condition of air blow machine operation in Table 3.

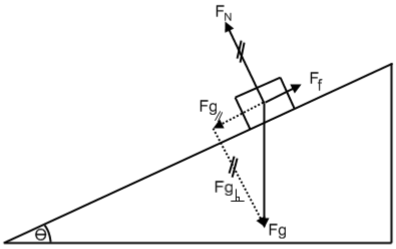


Figure 4. Object on inclined plane illustrated as the dry sliding phenomenon between modified rail and cover outlet product on air blow machine

Selection for speed parameter is based on calculation according to Figure 4 scheme. Equation (1) shows the force resultan on y-axis and Equation (2) shows the force resultan on x-axis direction. Where $\boldsymbol{F_N}$ is the normal force and $\boldsymbol{F_g}$ is the weight [7]. Assuming if the cover outlet product was moving without the initial velocity then the sliding acceleration ($\boldsymbol{a}$) value can be obtained according to Equation (3). Where $\boldsymbol{t}$ is sliding time and $\Delta\boldsymbol{d}$ is sliding distance from production parameter data in Table 3.

$$\sum \boldsymbol{F_y} = \boldsymbol{F_N} - \boldsymbol{F_{g\,(y-axis)}} = \boldsymbol{m.a_{(y-axis)}} = \boldsymbol{0} \quad (1)$$

$$\sum \boldsymbol{F_x} = \boldsymbol{F_f} - \boldsymbol{F_{g\,(x-axis)}} = \boldsymbol{m.a_{(x-axis)}} \quad (2)$$

$$\boldsymbol{t} = \sqrt{\frac{\boldsymbol{2.\Delta d}}{\boldsymbol{a}}} \quad (3)$$

Kinematic friction coefficient can be obtained from derivation of Equation (2) which denoted in Equation (4). Then the sliding velocity ($\boldsymbol{v}$) can be obtained using Equation (5). The angular velocity ($\boldsymbol{\omega}$) can be derived from Equation (6) using actual wear track occur ($\boldsymbol{R}$) in Table 2.

$$\boldsymbol{\mu_k} = \frac{\boldsymbol{g.\sin\theta + a}}{\boldsymbol{g.\cos\theta}} \quad (4)$$

$$\boldsymbol{v} = \boldsymbol{a.t} \quad (5)$$

$$\boldsymbol{v} = \boldsymbol{R}.\boldsymbol{\omega} \tag{6}$$

Table 6 shows the experiment parameter where Normal force derived from Equation (2) and the disc spin parameter input obtained from Equation (6).

Table 6. Experiment parameter

Normal force (N)	0.0785
Pin cycle time (min)	3
Wear track radius (mm)	17.5
Condition	Dry sliding
Temperature	Room temperature
Disc spin speed (rpm)	151 rpm

2.4. Conducting the experiment

The experiment was conducting using a pin on disc tribometer with 151 rpm speed, 8 gr load and testing time 3 min for each pin specimen. These parameters are kept constant in each test. Friction that occurs between the pin and disc during the test will result in surface erosion of the pin and disc specimen. Wear measurement is focused on reducing the mass ($\Delta \boldsymbol{m}$) of both disk specimens after each test with 5 pins. The output of the test results in the form of data on the average change in the mass of the two disk specimens. The data is then converted to a volume reduction value ($\Delta \boldsymbol{V}$). The volume reduction value is obtained from the mass reduction value ($\Delta \boldsymbol{m}$) divided by the density of each disc material. Those calculation can be seen in Equation (7). Then the total volume reduction value is used to calculate the wear rate and the specific wear rate. The results of the analysis of these calculations will be used to calculate the service life of the rail according to the allowable wear limit.

$$\Delta \boldsymbol{V} = \frac{\Delta \boldsymbol{m}}{\boldsymbol{\rho}} \tag{7}$$

Wear rate (W) can be calculated from Equation (8). Wear rate value obtained from the wear volume divided by sliding distance [8].

$$\mathbf{W} = \frac{\Delta \boldsymbol{V}}{\boldsymbol{s}} \tag{8}$$

Meanwhile the specific wear rate (k) can be obtained from Equation (9), Mass change as the pin travelled divided by normal load, material density and sliding distance [9].

$$\mathbf{k} = \frac{\Delta \boldsymbol{m}}{\boldsymbol{\rho}.\boldsymbol{s}.\boldsymbol{F_N}} \tag{8}$$

2.5. Experiment data validation

The validity of this study is the data on the amount of each disk mass reduction against the amount of time the correlation is calculated using the Pearson formula (r count). The rule of decision is if r count> r table, then it is valid. If r count < r table, then it is not valid. Distribution (Table r) for $\alpha = 0.05$ and degrees of freedom (dk = n - 2). Validation test using MS.Excel software with the formula = Pearson (array cell1; array cell2) [10-12].

3. Result and Discussion

Experiment data using 60 pin specimen presented in form of mass difference in disc specimen. Table 7 and Table 8 shows the mass difference for disc specimen 1 and disc specimen 2.

Table 7. Wear experiment data result for disc 1 (SUS 304)

No	Test no.	Time total (min)	m_1 (gr)	m_2 (gr)	Δm (gr)
1	1-5	15	121.0990	121.0880	0.0110
2	6-10	15	121.0880	121.0846	0.0034
3	11-15	15	121.0846	121.0841	0.0005
4	16-20	15	121.0841	121.0833	0.0008
5	21-25	15	121.0833	121.0794	0.0039
6	26-30	15	121.0794	121.0780	0.0014

Table 8. Wear experiment data result for disc 2 (SUS 410)

No	Test no.	Time total (min)	m_1 (gr)	m_2 (gr)	Δm (gr)
1	1-5	15	116.0067	116.0061	0.0006
2	6-10	15	116.0061	116.0059	0.0002
3	11-15	15	116.0059	116.0055	0.0004
4	16-20	15	116.0055	116.0053	0.0002
5	21-25	15	116.0053	116.0048	0.0005
6	26-30	15	116.0048	116.0042	0.0006

Experiment validation using Pearson method can be seen in Table 9. Distribution (Table r) for α = 0.05 and degrees of freedom (dk = n - 2) obtained r table 0.8114 at n = 6. The research data is declared valid because result of each r count>r table.

Table 9. Data validation result

No	X (Δm) disc 1	X (Δm) disc 2	Y (time)
1	0.011	0.0006	15
2	0.0144	0.0008	30
3	0.0149	0.0012	45
4	0.0157	0.0014	60
5	0.0196	0.0019	75
6	0.021	0.0025	90
r_{xy}	0.971	0.983	

Distance calculation can be obtained by the addition between first test distance and second test distance. Then those calculation will be added to third test and so on until thet sisth test. The total distance travelled during pin on disc shows 1494302.04 mm or 1494.3 m. Table 10 shows the disc distance on the experiment.

Table 10. Disc mass and distance

No	Test No.	m_2 (gr) disc 1	m_2 (gr) disc 2	Time (min)	Distance (mm)
1	1-5	121.0880	116.0061	15	249050.34
2	6-10	121.0846	116.0059	15	249050.34
3	11-15	121.0841	116.0055	15	249050.34
4	16-20	121.0833	116.0053	15	249050.34
5	21-25	121.0794	116.0048	15	249050.34
6	26-30	121.0780	116.0042	15	249050.34
Sum					1494302.04

Figure 5 shows the material mass decrease to increasing disc traveled. Based on Figure 5, it can be seen that the two disk materials experience a decrease in mass with increasing distance traveled. The disc 1 (SUS 304) material experienced a significant change in mass from the initial weight of the specimen compared to the disc 2 (SUS 410) material. The average mass change for SUS 304 in Table 7 and Table 8 was 0.0035 gr while SUS 410 was only 0.0004 gr.

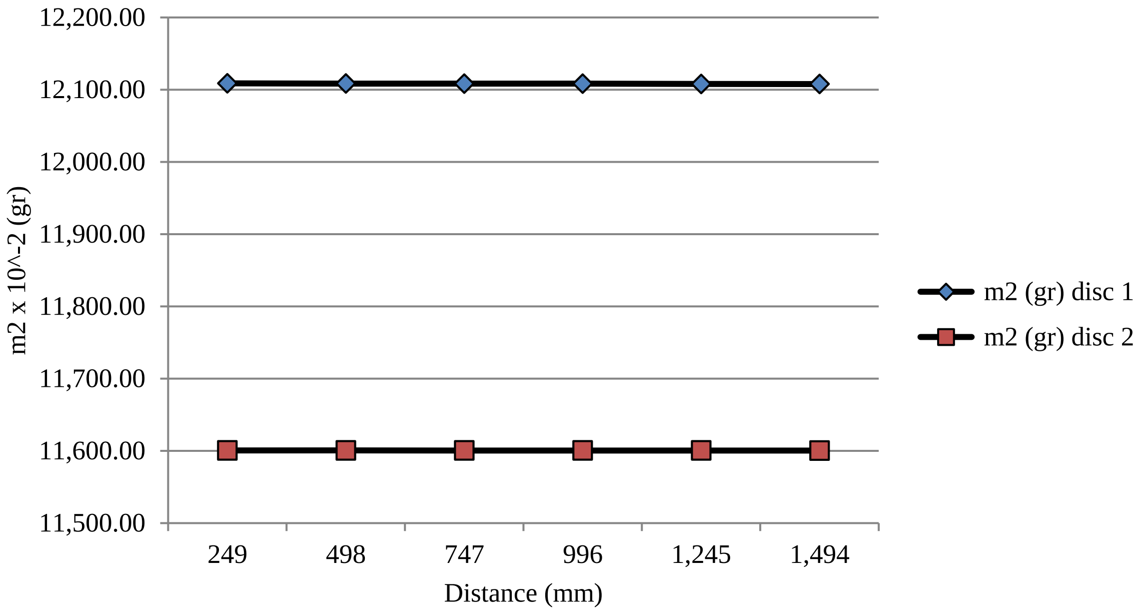


Figure 5. Disc 1 (SUS 304) and disc 2 (SUS 410) mass decrease to distance traveled

Table 11 denote the wear volume data based on experiment and calculation from Equation (7). The wear volume obtained in the first test will be added to the wear volume in the second test. Then, the total wear volume obtained from the first and second tests will be added to the third test and so on until the sixth test. Thus, the total wear volume obtained from each test on the chart is in the sixth test. The most obvious comparison on the graph is the wear volume value of the SUS 304 stainless steel disc which has increased continuously more than the wear volume of SUS 410. The total wear volume of SUS 304 is 2.625 mm^3. SUS 410 is 0.3204 mm^3. The average volume change of SUS 304 is 0.4375 mm^3. While the SUS 410 is 0.0534 mm^3. Figure 6 illustrates the wear volume change to time.

Table 11. Wear volume

No	Test No.	ΔV disc 1 (SUS 304) (mm^3)	ΔV disc 2 (SUS 410) (mm^3)
1	1-5	1.375	0.0769
2	6-10	0.425	0.0256
3	11-15	0.0625	0.0513
4	16-20	0.1	0.0256
5	21-25	0.4875	0.0641
6	26-30	0.175	0.0769
Average		0.4375	0.0534

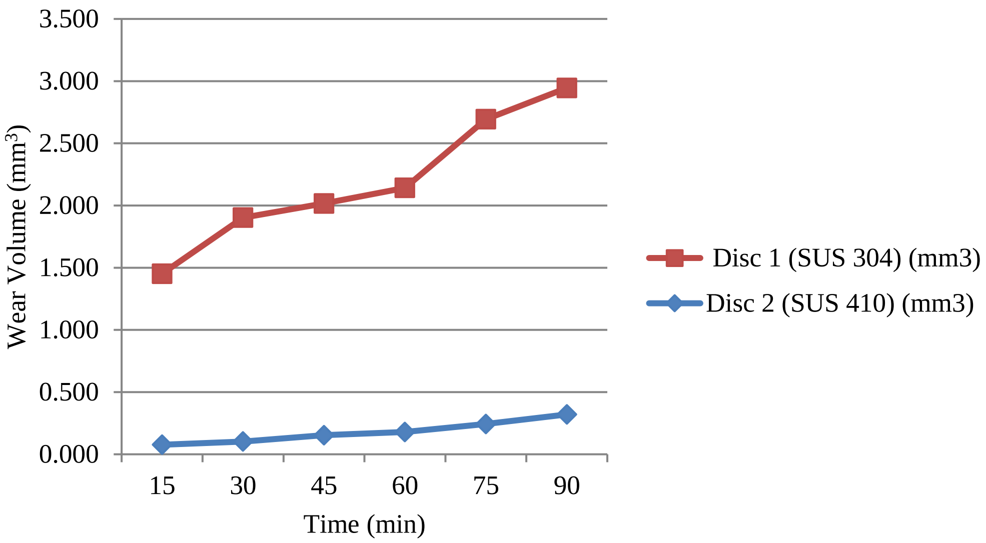


Figure 6. Wear volume graph comparison

The results of the wear rate test on the rail material SUS 304 and the alternative material SUS 410 show a significant difference. The graph of mass and volume changes as described shows that SUS 304 has a greater change in mass and volume than SUS 410. These differences have an effect on the rate of wear. The wear rate for the SUS 304 material is 0.00486 (mm3 / minute) while for the SUS 410 material it is 0.000593 (mm3 / minute). There is also a significant difference in the results of the calculation of specific wear rates. The specific wear rate for the SUS 304 material is 0.0037 (mm3 / Nm) while for the SUS 410 material is 0.000455 (mm3 / Nm). The results of these calculations indicate that the quality of the SUS 410 test material has better wear resistance with a decrease in the wear rate of 87.7% of the actual material wear rate. One thing is influenced by the hardness characteristics of the test material. SUS 410 material has a higher level of hardness than SUS 304 so that it greatly affects the wear rate because the higher the hardness, the higher the level of wear resistance. The wear rate and specific wear rate result are shown in Figure 7.

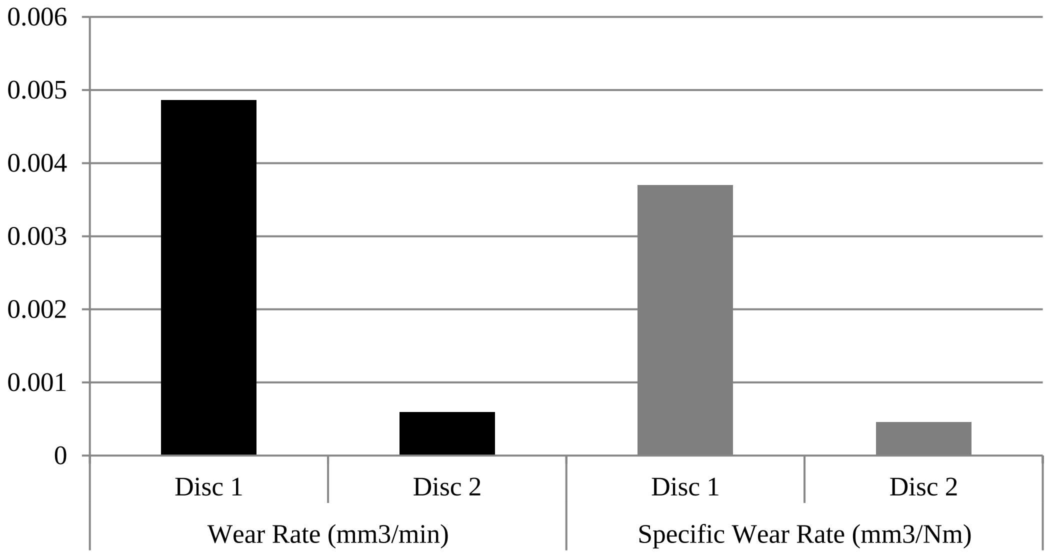


Figure 7. Wear rate and specific wear rate diagram

4. Conclusion

Based on the analysis of the test results of the Air Blow Cover Outlet engine rail material wear, stainless steel SUS 304 and its alternative material, SUS 410 with contact material PPS Ryton R-7-120BL can be concluded that the alternative material SUS 410 have a better quality in terms of wear rate and lifetime. This statement consistent with another research result which involved another material in contact such as electrical component, polimers and drilling equipment [13-15].

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