A STATISTICAL MODEL FOR DETERMINING FRICTION AND WEAR OF SK11 BALL BEARING IN NANOPARTICLES-ENHANCED ENGINE OIL

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "A Statistical Model For Determining Friction And Wear Of SK11 Ball Bearing In Nanoparticles-enhanced Engine Oil" is the result of my own work except as cited in the references

Signature	:	....
Name	:	....
Date	:	....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature :. ....
Name of Supervisor : ....
Date : ....

DEDICATION

To my beloved family and friends.

ABSTRACT

Hexagonal Boron Nitride is one of nanoparticles types that widely used in tribology industry for improvement in tribological performance. In order to reduce the COF and wear scar of ball bearing, hBN is added into the engine oil. So, the Four-Ball Tester experiment is running in order to predict the friction and wear reduction of SK11 ball bearing. The experiment is carried with loads of 100N, 300N, 500N, speed of 100 rpm, 300 rpm, 500 rpm and temperature at room temperature, 50°C and 100°C. In addition, the portable microscope will be used to test the wear scar diameter or the worn that form on the surface of ball bearing. Hence, this experiments were conducted based on Taguchi method. A L9 Orthogonal array was selected for design of experiment. The analysis that conducted for this experiment is ANOVA which is used in investigating the influence of applied load, speed and temperature on friction coefficient and wear rate. Besides, the regression model were developed for COF and wear rate. In this research, it is observed that applied load has the highest influence in COF and wear rate followed by speed and temperature. Lastly, the experimental result were validated by the confirmation tests.

ABSTRAK

Heksagon Boron Nitride adalah salah satu jenis nanopartikel yang digunakan secara meluas dalam industri tribologi untuk meningkatkan prestasi bahan. HBN ditambah ke dalam minyak enjin untuk mengurangkan pekali geseran dan kadar kehausan bebola. Jadi, eksperimen "Four-Ball Tester" dijalankan untuk memastikan pengurangan pekali geseran dan kadar kehausan bebola jenis SK11. Eksperimen ini dijalankan dengan menggunakan parameter yang berbeza iaitu beban 100N, 300N, 500N, kelajuan 100 rpm, 300 rpm, 500 rpm dan suhu pada suhu bilik, 50 ° C dan 100 ° C. Di samping itu, mikroskop mudah alih juga digunakan untuk menguji diameter kehausan bebola yang terbentuk di atas permukaan bebola. Oleh itu, eksperimen ini telah dijalankan menggunakan kaedah Taguchi. L9 Orthogonal pelbagai telah digunakan untuk reka bentuk eksperimen. Analisis yang dijalankan untuk eksperimen ini adalah ANOVA yang mana telah digunakan dalam menyiasat pengaruh beban, kelajuan yang digunakan dan suhu ke atas pekali geseran dan kadar kehausan bebola. Selain itu, model regresi juga telah dibentuk untuk pekali geseran dan kadar kehausan bebola. Dalam kajian ini, didapati bahawa beban yang dikenakan memberikan pengaruh yang tertinggi kepada pekali geseran dan kadar kehausan dan diikuti oleh kelajuan dan suhu. Akhir sekali, keputusan eksperimen telah disahkan dengan menggunakan ujian pengesahan.

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LIST OF ABBREVIATION

hBN	Hexagonal Boron Nitride
DOE	Design of Experiment
ANOVA	Analysis of Variance
OA	Orthogonal Array
COF	Coefficient of Friction
WSD	Wear Scar Diameter
S/N	Signal to Ratio
CuO	Copper Oxide
WVO	Waste Vegetable Oil
SEM	Scanning Electron Microscopy

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF STUDY

Lubricant or engine oil is used for lubrication in internal combustion engine system. It creates a separating film between surfaces of moving parts to minimize direct contact from one part to another part. It will reduce the friction coefficient and wear reduction from forming, thus protect the engine.

Over a past few decades, nanotechnologists did some great research on nanoparticles because of their special physical and chemical properties. So, they have made an investigation on the mixture between nanoparticles with conventional diesel engine oil. The mixture showed a lot of improvements happen especially on properties of the engine oil which are under extreme pressure, wear resistance and friction reduction properties. The size of nanoparticles play main role in improvement of lubricant properties. Because of their small size, it allows them enter into the contact interface for load bearing and lubricating easily. Besides that, there are a lot of types of nanoparticles that are used in the improvement of engine oil properties. For example, CuO as addictive in the engine oil.

The reduction of friction coefficient and anti-wear are important in lubricant because it can affect the effects of tribological performance of engine oil. The performance of engine oil is better when the friction coefficient is low and the worn surface that formed on bearing is small.

1.1 PROBLEM STATEMENT

Friction and wear are the important aspect in the engine oil performance. Existing engine oil is only effective at high load, speed and temperature. So, nanoparticles are decided to mix with the engine oil to improve the performance of engine right after startup.

Hence, Taguchi method is the method that will be used while doing the research because of the variance reduction for the experiment with optimum setting of control parameters.

1.2 OBJECTIVES

The objectives of this project are as follows:

1. To determine the optimal parameters for friction and wear reduction for SK11 ball bearing in the mixture of hexagonal boron nitride (hBN) and engine oil at low load, speed and temperature.
2. To propose mathematical model for determining wear and friction of SK11 ball bearing in the mixture of hexagonal boron nitride (hBN) and engine oil in Minitab software by using Taguchi method.

1.3 SCOPE OF PROJECT

This research is carried out to study the prediction for friction and wear of SK11 in nanoparticles-enhanced engine oil at low load, speed and temperature. The Four-Ball Tester experiment will be conducting for this research. The Minitab software and the Design of Experiment (DOE) under the Taguchi method will be used to set up the parameter for this research. The parameters that are going to be used in this study are load, speed and temperature. The Analysis of Variance (ANOVA) will be used to analyze the friction and wear of SK11 ball bearing in nanoparticles-enhanced engine oil.

CHAPTER 2

LITERATURE REVIEW

2.1 NANOPARTICLES AS ADDICTIVES IN ENGINE OIL

Over the past few decades, scientists and technologists have been carried out on the tribological properties of lubricants with different nanoparticles added in the engine oil. Nanoparticles are added into the engine oil because it can improve the properties of engine oil which can reduce coefficient of friction and wear. There are several chemical composition that can be used as addictive in engine oil. For example, metal sulfides such as MoS_2 is one of the chemical composition. Sulfur played an important role in the interaction between particles and molecules of lubricant because of the laminar structure. A tribofilm are formed on the friction surface after the tribochemical reaction take place between particles and the environment under the heat generated by friction and high pressure contact. The tribofilm has unique properties which are hardness, adhesion and roughness. For example, from Figure 2.1, adsorption film was formed after nano-MoS_2 reacted with lubricants (Wei Dai et al., 2016).

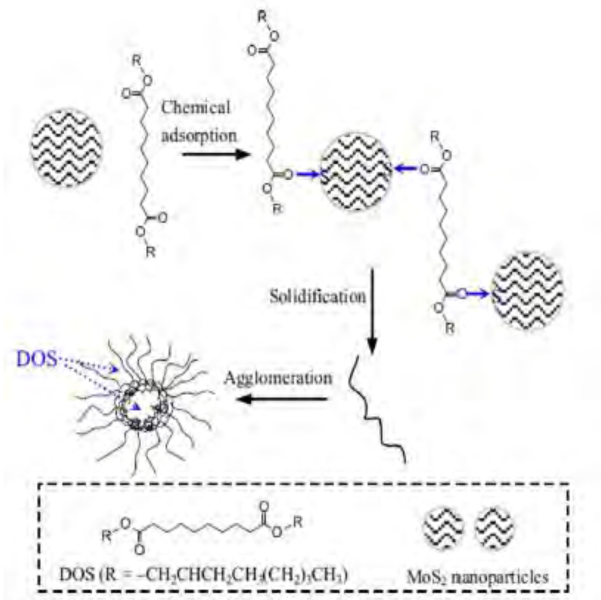

Figure 2.1 The formation of adsorption layer using MoS_2 nanoparticles (Wei Dai et al., 2016)

Next, MoS_2 is also most commonly used solid lubricant to improve performance of the process because it offers very low friction coefficient, high wear resistance and can withstand the heavy load (Gunda et al., 2016).

2.2 NANOPARTICLES AS FRICTION IMPROVER AND WEAR REDUCTION

Nanoparticles are used in the improvement of engine oil because by adding nanoparticles in engine oil, the coefficient of friction and wear will reduce. The properties of lubricant itself is reduced the friction between two surfaces and as anti-wear. The friction coefficient is lowest and wear is reduced on the friction surface that strong solid lubricating film formed during whole test because of the addictive compound effects, S-P addictive. As shown in the Figure 2.2, the coefficient of friction for HD 80w/90 type of engine oil is low because of addictive and Figure 2.3 for anti-wear comparison (Jiyuan et al., 2001). Besides that, normal lubricant (SAE grade 40) combined with amine phosphate and palm oil shows better results especially on reducing friction coefficient, reducing WSD, increasing FTP and reducing TAN value, besides also reducing the viscosity within the operating range. As shown in Figure 2.4, the different COF value between normal lubricant and lubricant with different types of addictive and Figure 2.5, for WSD vs percentage (%), e.g. sample D is normal lubricant with 0.5% Amine phosphate with 1% to

5% waste palm oil (WVO) with base lubricant, sample E is normal lubricant 0.5% Octylated/butylated diphenylamine addictive with 1% to 5% waste palm oil (WVO) with base lubricant (Kalam et al., 2011).

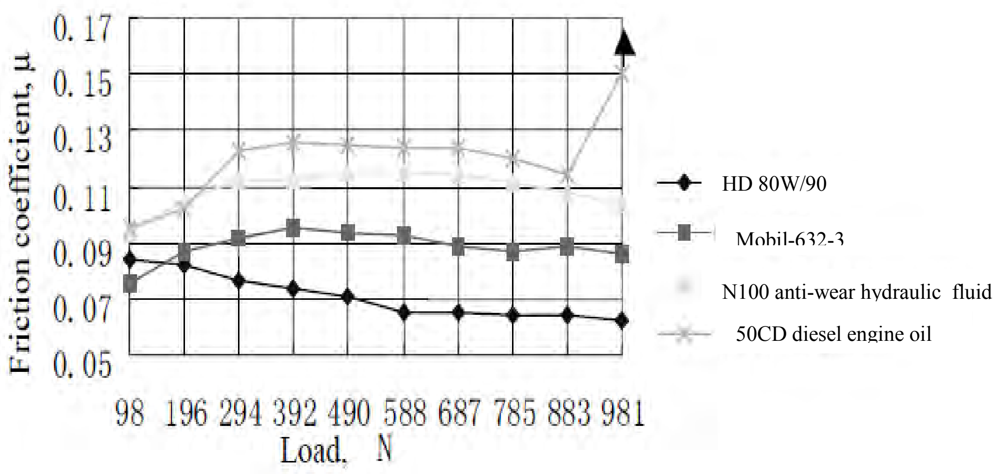

Figure 2.2 The load-friction coefficient curve of 4 oils (Jiyuan et al., 2001)

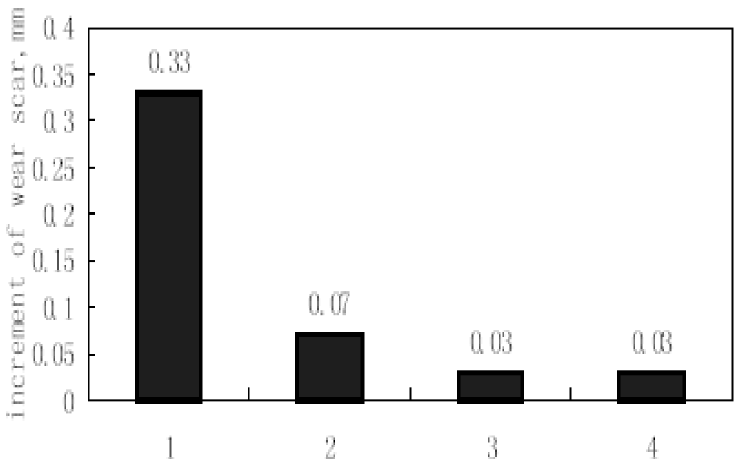

Figure 2.3 Comparison of anti-wear in 4 types of oil. 1. 50CD diesel engine oil, 2. N100 anti-wear hydraulic fluid, 3. mobil-632, 4. HD 80w/90 (Jiyuan et al., 2001)

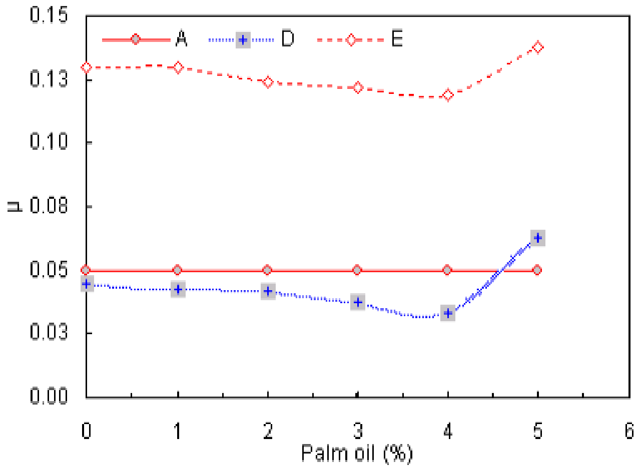

Figure 2.4 COF (μ) vs percentage (%) of palm oil in sample D (normal lubricant with 0.5% Amine phosphate with 1% to 5% waste palm oil (WVO) with base lubricant) and sample E (normal lubricant 0.5% Octylated/butylated diphenylamine addictive with 1% to 5% waste palm oil (WVO) with base lubricant) (Kalam et al., 2011)

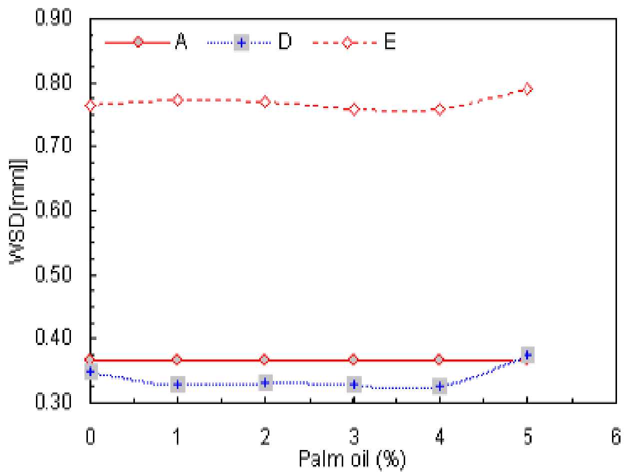

Figure 2.5 WSD vs percentage (%) (Kalam et al., 2011)

Suspension of 3% of CuO nanoparticle content with modified produced COF of 0.13 which is the best COF. It shows that the higher the concentration of CuO, the better the tribological properties and surface modification. It can be approved in the Figure 2.6 (Asrul et al, 2013). Besides that, the tribological properties is improved when nanoparticles was added into base oil especially for friction and wear reduction. In addition, CuO nanoparticles that added into the base oil reduced the COF value from 24% to 53% at 0.5% CuO concentration during the friction reduction test compared to the oil without nanoparticles (Pisal & Chavan, 2014).

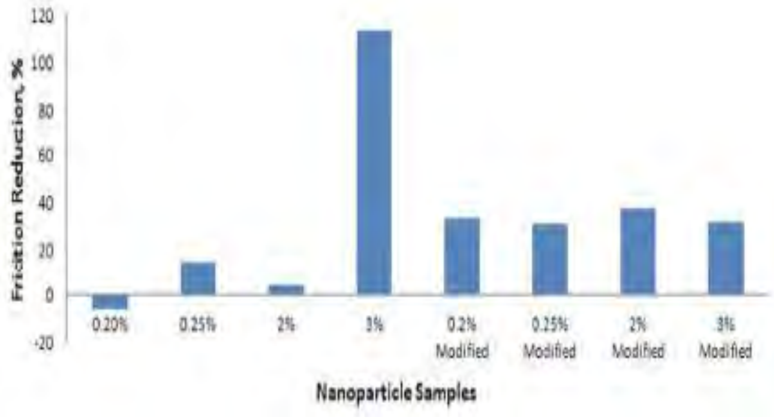

Figure 2.6 Friction reduction vs Nanoparticles samples (Asrul et al., 2013)

The friction coefficient value of the base oil is higher compared to the friction coefficient value of nano-BN oil during the test occur. Furthermore, the increase the concentration of BN nanoparticle addictive, the increase the value of the COF. The concentration nano-BN that are using in the test are 0.1wt.%, 0.5wt.% and 1.0wt.%. The result of the test can be seen in the Figure 2.7. Next, nano-BN also improve the anti-wear properties of base oil which has been confirmed from SEM, AFM and EDS about the worn surface. Figure 2.8 shown the worn surface before test while Figure 2.9 shown the worn surface after the surface was tested by using sample BN01 which contain 0.1wt% of BN (Wan et al., 2015).

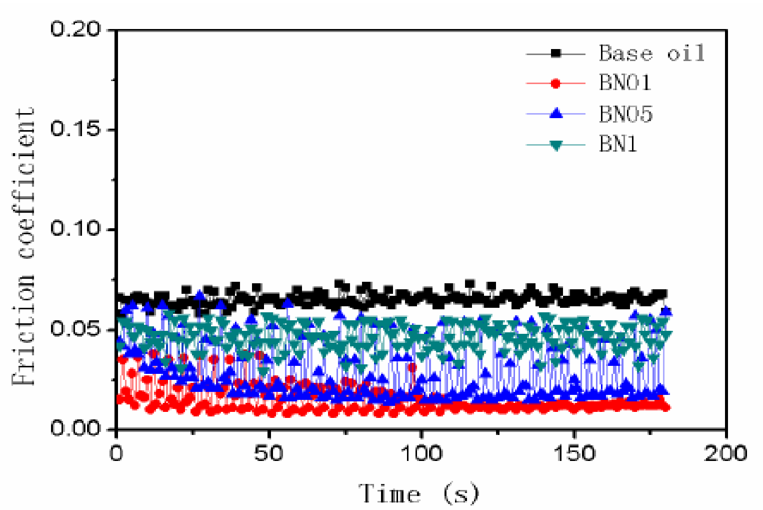

Figure 2.7 Friction coefficients of base oil and nano-BN vs time (Wan et al., 2015)

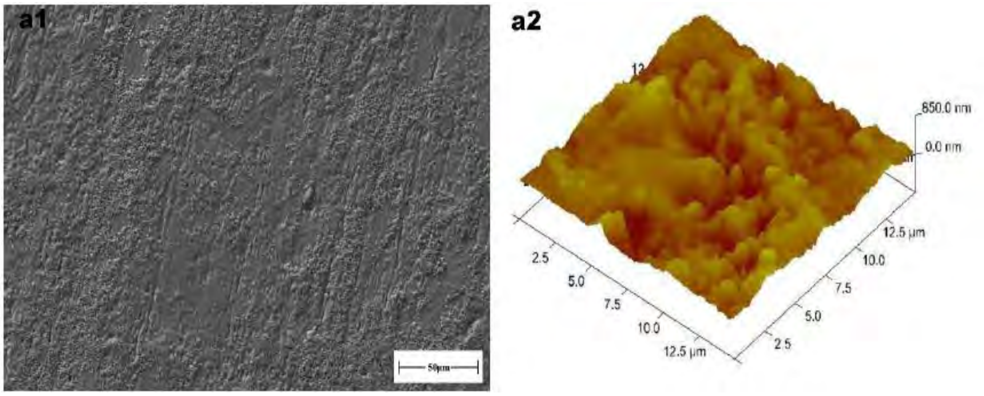

Figure 2.8 Example of worn surface before test with BN01 by using SEM and AFM (Wan et al., 2015)

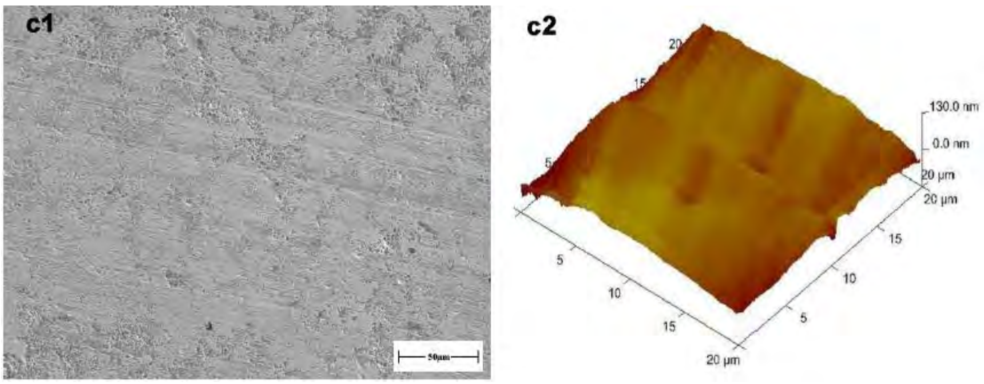

Figure 2.9 Example of worn surface after test with BN01 by using SEM and AFM (Wan et al., 2015)

For a few past decades, nanoparticles as addictive in the lubricant shows the effective decreasing in friction and wear. Metal, metal oxide, metal sulfide, carbonate, borate, carbon material and rare-earth compound have been one of the best addictive in improving the lubricant properties (Shahnazar et al., 2016).

2.3 FOUR BALL TESTER MACHINE

Four ball tester machine is specifically used to determine the friction coefficient and also the wear-preventing properties of various lubricant such as motor oil, cutting oil, hydraulic oil, greases and solid lubricant. Furthermore, it also can be used to determine the friction and wear characteristics of bearing materials. Besides that, it is also important to differentiate between the Four-Ball EP Tester and the Four-Ball Wear Tester. It is because the Four-Ball EP Tester is designed specifically for high test load. The Four-Ball Tester is automatic and can be controlled by using graphical interface $M4B^{TM}$ software (Garcia-Bustos et al., 2013). This machine used four balls which are three balls at the bottom and one ball on the top which is attached to the collate as shown in Figure 2.10 (Syahrullai et al., 2013)

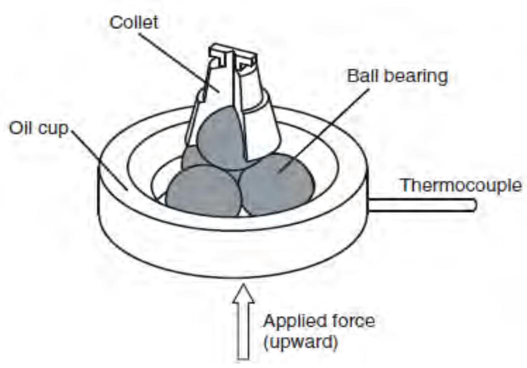

Figure 2.10 Schematic diagram for Four-Ball Tester (Syahrullai et al., 2013)

2.4 TAGUCHI METHOD

Taguchi method is developed by Dr. Taguchi Of Nippon Telephones and Telegraph Company which is based on Orthogonal Array (OA) experiments. This method gives much reduced variance for the experiment with optimum setting of control parameters. The combination between Design of Experiments (DOE) with optimization of control parameter to gain the best result is achieved in Taguchi method. OA provide a set of well balanced and Signal-to-Noise ratios (S/N), which are log functions of desired output. this is served as objective functions for optimization which is help in data analysis and optimum results prediction. This method has divided into three categories of quality characteristic in the S/N ratio which are the-lower-better, the-higher-the-better and the-nominal-the-best (Kapsiz et al., 2011).

DOE is a method that is denoted by "$L_a b_c$". L_a is the orthogonal arrays of variables, b is the levels of variables while c is variables numbers (Kondapalli et al., 2013). (Rao & Padmanabhan, 2012) says that the function of Taguchi method is to determine the optimum settings of input parameters and neglect the variation that has been caused by noise factor.

S/N ratio for COF was computed to quantify the optimal value to each design parameter which mean the greater the value of S/N ratio, the better the performance that will produce. Figure 2.11 is about the interaction plot of COF against three different parameter which are applied load (N), sliding speed (rpm) and sliding distance (km).

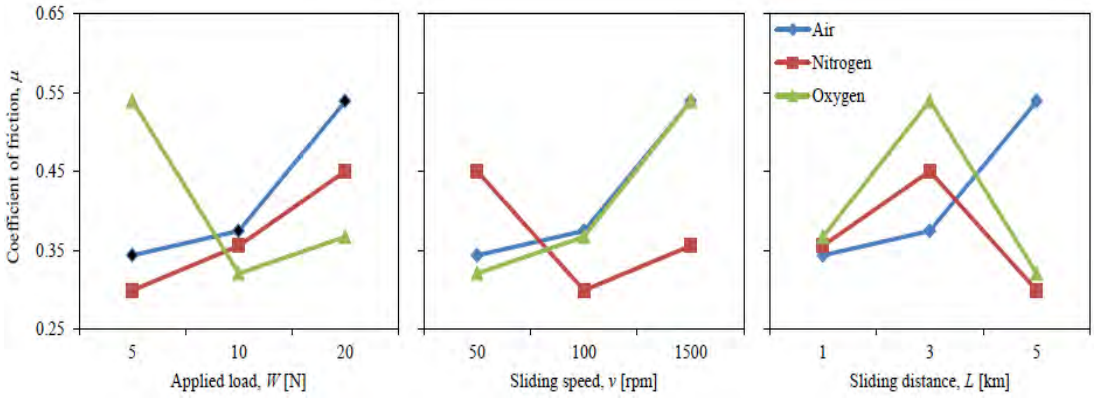

Figure 2.11 Interaction plot for friction coefficient (Rao & Padmanabhan, 2012)

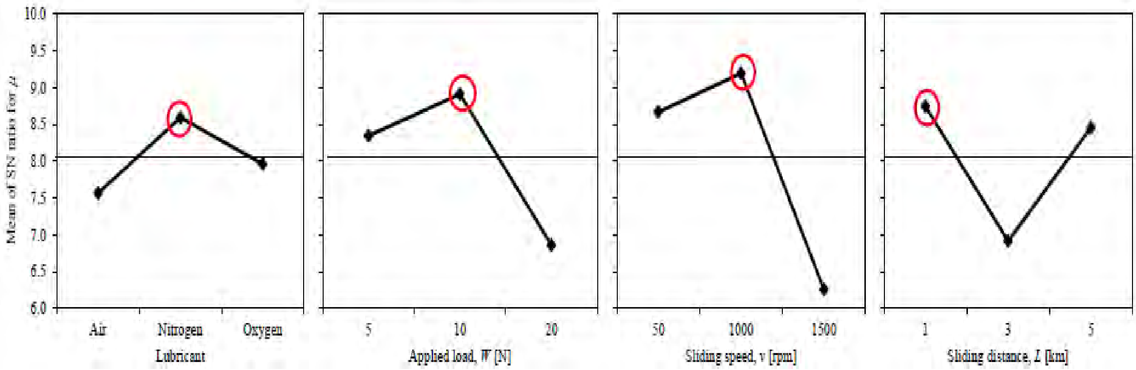

Figure 2.12 Mean of COF (Abdollah et al., 2013)

There red circle in the Figure 2.12 are shown the optimal design parameter after analysis by using S/N ratio (Abdollah et al., 2013). Next, other analysis can be obtained from Taguchi method is Analysis of Variance (ANOVA). (Julie et al., 2007) said that the function ANOVA is to determine the percentage contribution of each parameter against a stated level of confidence for a result of experiment. Besides that, ANOVA also helps in testing of importance of all main factors and their interactions. It can be done by comparing the mean square against an estimate of the experimental errors at specific confidence level. Calculate the total sum of squared deviation SS_T from the total mean S/N ratio n_m as follows: