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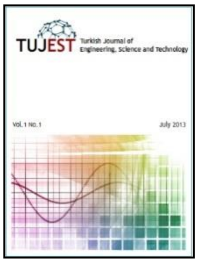

Experimental Optimization of Wear Parameters of Piston Ring Coated With Molybdenum

Ferit Ficici[a*], Sezer Kurgun[a]

[a]*Sakarya University, Faculty of Technology, 54187, Sakarya, Turkey*

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Abstract

In this study examine an experimental study of wear behaviour ofpiston ring. Reciprocating wear process parameters are optimized for minimum weight loss based on L27Taguchi design with three process parameters, load, temperature and revolution. It is observed that load have the most significant influence on weight loss of piston ring. The experimental results are in good agreement with the values from the theoretical model.

1. Introduction

The piston ring pack must fulfill these three roles with a minimum of frictional power loss, most notably at the sliding interface with the cylinder wall, and a minimum of wear in order to maximize component life. Unfortunately, the piston ring pack is one of the largest sources of friction in the internal combustion engine over the normal range of engine speeds and loads encountered in service [1-3].

The piston ring is the most complicated tribological component in the internal combustion engine to analyze because of large variations of load, speed, temperature and lubricant availability. In one single stroke of the piston, the piston ring interface with the cylinder wall may experience boundary, mixed and full fluid film lubrication [4].
Taguchi's experimental design method can further simplify the experiments by extending the application of fractional factorial design to the use of orthogonal array. Hence, this method is a simple, efficient and systematic approach to optimize designs for performance, quality and cost. It is for this reason that Taguchi's method has been used for a wide range of industrial applications worldwide [5-7].

In this study, input parameters of load, temperature and revolution have been optimized to determine minimum weight loss of piston ring coated for with molybdenum by using Taguchi's design methodology.

2. Experimental Work

The wear tests were conducted under lubricated sliding conditions in accordance with ASTMG133-05 standard. The reciprocating wear testing machine is shown in Figure1. Load on the pin was applied using dead weights by way of lever arm loading system. Test conditions are presented Table 1.

* Corresponding Author:
Ferit Ficici, e-Mail: fficici@sakarya.edu.tr

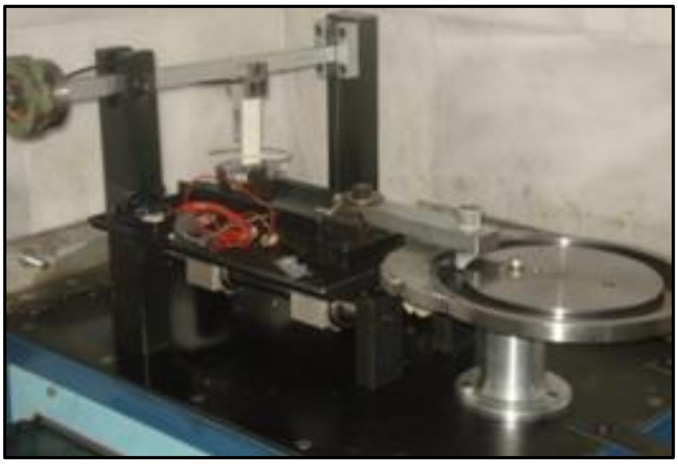

Figure1. Piston ring reciprocating liner wear test machine

Table 1. Tribotest conditions

Test specifications	Values
Load, N	60-80-100
Temperature, °C	40-60-80
Stroke, mm	100
Oil supply, ml/h	0.5
Distance, m	2000
Oil, SAE	10W40

The upper specimens are ring samples cut directly from the production-molybdenum coated piston rings. The lower specimens with a shape of flat cylindrical made of a production cast iron cylinder bore samples material composed of pearlite, ferrite, and graphite structures. Piston rings manufactured by molybdenum coating procedures, were used with the same cast iron cylinder bore to form the tribo-contact system. Piston ring and cylinder liner specifications are shown in Table 2. Also chemical composition of piston ring and cylinder liner are presented in Table 3.

Table 2. Piston ring and cylinder liner specifications[8]

Sample	Material	Surface treatment	Hardness ($HV_{0.1}$)	Roughness(R_a,µm)
Ring	Cast iron	Molybdenum coated	500	0.121
Liner	Cast iron	Honing	20.3	1.052

Table 3. Chemical compositions of piston ring and cylinder liner [8]

Sample	C	Cu	S	Mn	Si	P	Fe
Ring	3.62	0.117	0.043	0.416	2.4	<1	Balance
Liner	3.45	0.1	0.05	0.4	2.1	0.4	Balance

The PO Maxima 10W40 engine oil, was selected as test lubricants. Tribo-systems consisting of the tribomates and lubricant were operated in a reciprocating tribotester. Weight loss of the all samples, were determined as a function of load, temperature and revolution. Weighting was performed with an analytic balance with asensitive of 0.1 mg. 10W40 oil was mineral oil based. Oil property is shown in Table 4.

Table 4. 10W40 Oil properties [8]

SAE Viscosity Grade		
Density, 15°C kg/m^3	ASTM 4052	0.873
Flash Point , COC, °C	ASTM D 92	226
Viscosity Index	ASTM D 2270	154
Pour Point, °C	ASTM D 97	-33
Kinematic Viscosity		
40°C mm^2/s	ASTM D 445	91,18
100°C mm^2/s		13.76

2.1. Design of experiments

The method of Taguchi for four factors at three levels was used for the elaboration of the plan of experiments. Table 5 indicates the factors to be studied and the assignment of the corresponding levels. By levels we mean the values taken by the factors.

Table 5. Control Factors and their levels

Control factor	Level			
	I	II	III	Units
A:Load	60	80	100	N
B:Temperature	40	60	80	^{o}C
C:Revolution	60	90	120	Rev/min

The total degree of freedom (DOF) for four factors, each at three levels and three interactions in 20. Therefore, a three-level Taguchi orthogonal array (TOA) with at least 20 DOF was chosen. The L_{27} OA is given in Table 6.

Table6. L_{27} (3^{13}) orthogonal array

Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7	Factor8	Factor9	Factor 10	Factor 11	Factor 12	Factor 13
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	2	2	2	2	2	2	2	2	2
1	1	1	1	3	3	3	3	3	3	3	3	3
1	2	2	2	1	1	1	2	2	2	3	3	3
1	2	2	2	2	2	2	3	3	3	1	1	1
1	2	2	2	3	3	3	1	1	1	2	2	2
1	3	3	3	1	1	1	3	3	3	2	2	2
1	3	3	3	2	2	2	1	1	1	3	3	3
1	3	3	3	3	3	3	2	2	2	1	1	1
2	1	2	3	1	2	3	1	2	3	1	2	3
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2	3	1	2	1	2	3	3	1	2	2	3	1
2	3	1	2	2	3	1	1	2	3	3	1	2
2	3	1	2	3	1	2	2	3	1	1	2	3
3	1	3	2	1	3	2	1	3	2	1	3	2
3	1	3	2	2	1	3	2	1	3	2	1	3

3	1	3	2	3	2	1	3	2	1	3	2	1
3	2	1	3	1	3	2	2	1	3	3	2	1
3	2	1	3	2	1	3	3	2	1	1	3	2
3	2	1	3	3	2	1	1	3	2	2	1	3
3	3	2	1	1	3	2	3	2	1	2	1	3
3	3	2	1	2	1	3	1	3	2	3	2	1
3	3	2	1	3	2	1	2	1	3	1	3	2

This array specifies 27 experimental tests and has 10 columns. Since each interaction has 4 DOF, a total of 6 columns (two columns for each interaction) was needed for assigning the interactions. Using a triangular table for three-level TOA the interacting columns in L_{27} TOA were identified and parameters were assigned to columns accordingly (Figure2) [9].

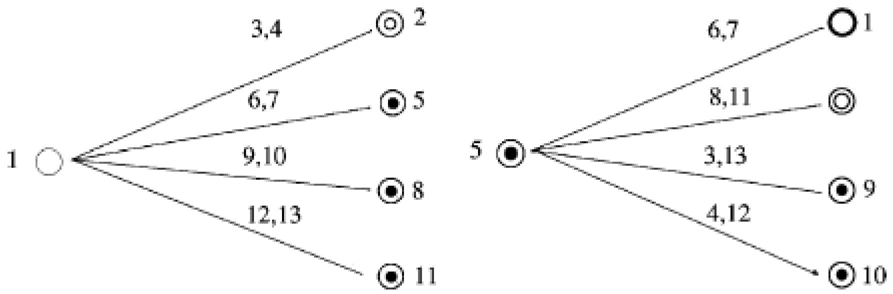


Figure 2. Linear graphs for L_{27} array [10].

In the Taguchi method, the experimental results are transformed into a signal-to-noise (S/N) ratio. The use of S/ N ratio to measure the quality characteristics deviating from the desired values. There are three categories of quality characteristic in the analysis of the S/N ratio, i.e., the smaller is better, the larger is better, and the nominal is better (Table7).

The S/N ratios of weight loss are calculated according to the equation:

Smaller is better characteristic:

$$\frac{S}{N} = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} yi^2\right) \quad (1)$$

Furthermore, a statistical analysis of variance (ANOVA) is performed to identify the process parameters that are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted to a useful level of accuracy. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

Table 7. Experimental lay out and results with calculated S/N ratios for weight loss

Load (N)	Temperature (ºC)	Revolution (rev/min)	Piston ring S/N ratios
60	40	60	54.54
60	40	90	58.98
60	40	120	60.68
60	60	60	53.97
60	60	90	56.88
60	60	120	58.16

60	80	60	68.12
60	80	90	70.10
60	80	120	73.60
80	40	60	56.08
80	40	90	56.30
80	40	120	56.39
80	60	60	56.03
80	60	90	56.15
80	60	120	56.24
80	80	60	56.35
80	80	90	56.44
80	80	120	56.58
100	40	60	49.59
100	40	90	50.10
100	40	120	50.44
100	60	60	48.82
100	60	90	49.52
100	60	120	49.80
100	80	60	50.86
100	80	90	51.58
100	80	120	52.18

3. Results and Discussion

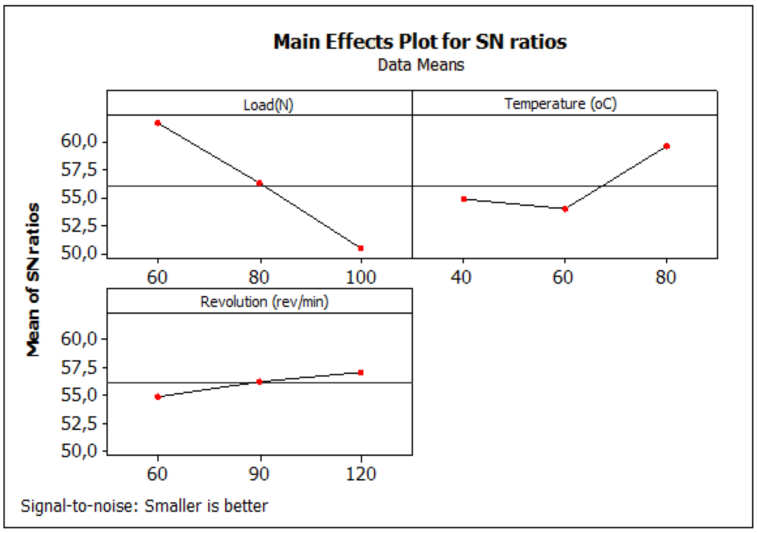
The analysis was done using MINITAB 16.1. Before any attempt is made to use this simple model as a predictor for the measure of performance, the possible interactions between the control factors must be considered. Table 7 shows the experimental array and results with calculated S/N ratios for weight loss of piston ring

Analysis of the influence of each control factor on the weight loss was carried out with the S/N response table. The control factors were classified in relation to the difference values. The response tables for weight loss is also presented in Table 8.It could be seen from this table that the factor Load had the strongest influence on the weight loss.

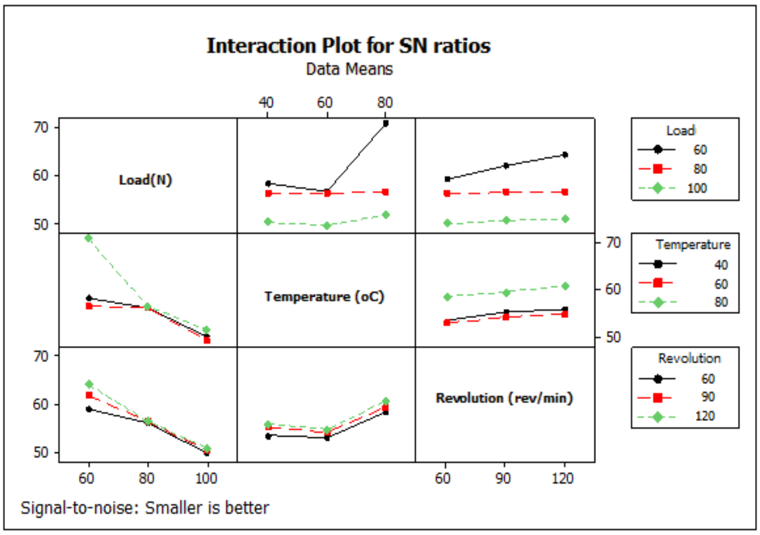
The main effect and interaction plots for S/N ratios are shown in Figs. 3a, 3b weight loss. Optimal process conditions of these control factors could be easily decided from these graphs.

Table 8. S/N response table for weight loss of piston ring

Level	Load (N)	Temperature (°C)	Revolution (rev/min)
1	53.71	46.48	50.26
2	53	51.85	47.61
3	43.6	51.98	52.44
Delta	10.11	5.5	4.82
Rank	1	2	3



(a)



(b)

Figure 3. (a)Main effect S/N ratio plot (b) interaction plot for weight loss of the piston ring.

The response graph shows the change of the S/N ratio when the setting of the control factor is changed from one level to the other. The best weight loss value was at the higher S/N values in the graphs. It could be seen in Figs. 2a, 2b, that the optimum process condition for piston ring became $A_1B_3C_3$ for main control factors. That is, the optimal process parameters for the weight loss is the load at level 1, the temperature at level 3, and the revolution at level 3.

4. Conclusion

The results are summarized as follows:

- Taguchi's orthogonal design method is suitable to statically analyze the tribological behavior of piston ring.
- The optimal combination of parameters is found to be $A_1B_3C_3$ (lowest level of load, highest level of temperature and highest level of revolution).
- Generally, it was observed that the load control factor have significant influence on the weight loss of piston ring.

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