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Wet Sliding Wear Optimization of Gray Cast Iron using Taguchi Technique

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ABSTRACT:

This paper details the investigation of wear characteristics of gray cast iron under dry, SAE15W40 and SAE20W40 oil lubricated sliding conditions. The effects of applied load, sliding speed and sliding distance on the specific wear rate of gray cast iron were studied using pin-on-disc wear testing machine. The experimental data were analyzed by using the robust technique of Taguchi's orthogonal arrays. The specific wear rate was analyzed using signal to noise ratio and analysis of variance.

KEYWORDS:

Gray cast iron; Specific wear rate; Taguchi technique; Signal to noise ratio; Analysis of variance

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1. Introduction

Gray Cast Iron (GCI) is one of the most important materials which are often used in automobiles. GCI is an inexpensive material and it is readily available. Some engineering applications of GCI are cylinder linear, pressure plate, diesel engine components, flywheel, and engine blocks. It has excellent engineering properties such as high tensile strength, vibration damping and good thermal stability. Fabrication of GCI is simple and most economical. Its specific characteristic includes excellent casting, no freezing contraction and low melting point. The property of GCI depends on volume fraction and graphite morphology. The addition of silicon into GCI improves the wear resistance [1]. According to Obidiegwu [2], addition of periwinkle shell into GCI has influence on its mechanical properties. The result suggests that carbon, manganese and silicon contents decrease with increasing amount of the periwinkle shell. The hardness was found to decrease while the tensile strength increased. According to Prasad [3], the sliding wear behaviour of GCI was tested for both dry and lubricant conditions at different ranges of sliding speed and applied pressure. The result suggests that when graphite particles were added to the oil lubricant, it caused further reduction in wear rate. This is due to enhanced properties of more stable lubricant film formation when graphite is added.

Chwala et al [4] discussed about the comparison between stainless steel 304 and GCI in which the wear parameter was tested at varying sliding speed and applied loads. The result suggested that the wear parameter of GCI was lesser than the stainless steel 304. Design of experiments (DoE) is an extremely powerful statistical method. It consists of series of tests in which input variables can be changed and data are collected in the same run. The Taguchi technique is devised for process optimization and identification of optimal combination of the factors for a given response. This technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments [5, 6]. Adhesive wear is defined as the transfer of material from one surface to another during relative motion as a result of localized bonding between contacting surfaces. Particles that are removed from one surface are either permanently or temporarily attached to the other surface. Adhesive wear occurs when surfaces slide against each other and the pressure between the contacting asperities is sufficiently high enough to cause local plastic deformation. Hardness of a material determines the real area of contact between asperities of contacting materials. Asperity hardness is considered to be more important than bulk hardness [7, 8].

Based on literature review, there is little evidence that the use of principles such as DoE for optimising the sliding wear characteristics of GCI. In this paper, the wear characteristics of GCI under dry, SAE15W40 and SAE20W40 oil lubricated sliding conditions. The effects of applied load, sliding speed and sliding distance on the specific wear rate (SWR) of GCI were studied using pin-on-disc wear testing machine. Taguchi's orthogonal arrays were used to analyse the experimental results. The SWR was analyzed using signal to noise (S/N) ratio and analysis of variance (ANOVA).

2. Experiments

The test specimen of GCI grade 200-250 was casted as a disc with the dimensions of 55mm (OD)×6mm (ID)×10 mm (thickness). The EN31 carbon steel counter face was prepared and hardened to get cylindrical pins of 6mm diameter and 60mm length. DoE helps to investigate the effects of input variables of wear parameter to give optimal values of an output response. The L27 orthogonal array was selected based on the DoE according to the standardization and degrees of freedom. The chosen applied load, sliding speed and sliding distance and their levels are given in Table 1. Condition L0 represents the dry sliding wear test. Conditions L1 and L2 represent the wet sliding under SAE15W40 and SAE20W40 lubricated oil respectively. The S/N ratio purely depends upon the quality characteristics. The "smaller is better" quality type is chosen for SWR of GCI. The room temperature of 33-35°C was maintained. The pin-on-disc tests were conducted as per ASTM G 99-05 standard. The experiments were conducted for both dry and lubricated conditions. Two different grades of oil such as SAE15W40 and SAE20W40 were selected. EN31 steel pin was used to determine the wear parameter which was held stationary in vertical position and pressed against the disc of GCI performing rotary motion. The pin was cleaned before and after the experiments with acetone to remove the contaminants. Weight of the specimen before and after the experiments was measured using analytical balance that had 0.0001gm of least count. A constant flow of liquid oil was allowed to flow on the disc performing rotary motion and tests were carried out.

Table 1: Process parameter and their levels

Level	Load, L (N)	Sliding speed, S (m/s)	Sliding distance, D (m)	Condition
1	15	0.5	300	L0
2	30	1.0	600	L1
3	45	1.5	900	L2

3. Results and Discussion

The pin-on-disc wear tests were conducted to study the effect of process parameters over the output response characteristics. The experimental results were analysed using L27 orthogonal array that has 27 rows corresponding to the number of experiments with 13 columns and 3 levels. The S/N ratio of the response characteristics for each variable at different levels were calculated from the experimental data. In this study all the designs, plots and DoE analyses have been carried out using Minitab statistical software. SWR is calculated as per the standard formula and their S/N ratios are obtained using "smaller is better" criterion. The experimental results for SWR and their S/N ratios are given in Table 2.

3.1. Analysis of Signal-to-Noise (S/N) ratio

Based on the parameter influence, the rank has been generated as per Taguchi technique as shown in Table 3. The difference between two highest values in each column gives the delta value of corresponding parameter. According to the descending delta value, the rank was allotted. Load is the most influence parameter in the wear rate followed by sliding speed and sliding distance. This was derived by the following response graph procedure.

Table 2: Experimental results

Load, L (N)	Sliding Speed, S (m/s)	Sliding Distance, D(m)	Condition	SWR x 10^{-5} (mm^3/Nm)	S/N for SWR
15	0.5	300	L0	2.63	-8.40
15	0.5	600	L1	0.88	1.11
15	0.5	900	L2	1.42	-3.05
15	1.0	300	L1	13.23	-22.43
15	1.0	600	L2	1.97	-5.89
15	1.0	900	L0	0.59	4.58
15	1.5	300	L2	21.37	-26.60
15	1.5	600	L0	3.53	-10.96
15	1.5	900	L1	0.77	2.27
30	0.5	300	L0	7.94	-18.00
30	0.5	600	L1	0.58	4.73
30	0.5	900	L2	0.73	2.73
30	1.0	300	L1	1.15	-1.21
30	1.0	600	L2	4.19	-12.44
30	1.0	900	L0	466.52	-53.38
30	1.5	300	L2	21.60	-26.69
30	1.5	600	L0	339.99	-50.63
30	1.5	900	L1	3.38	-10.58
45	0.5	300	L0	0.77	2.27
45	0.5	600	L1	0.15	16.48
45	0.5	900	L2	1.53	-3.69
45	1.0	300	L1	0.88	1.11
45	1.0	600	L2	2.63	-8.40
45	1.0	900	L0	1698.31	-64.60
45	1.5	300	L2	0.33	9.63
45	1.5	600	L0	81.42	-38.21
45	1.5	900	L1	0.66	3.61

Mean S/N ratio were plotted on the basis of wear parameter and are shown in Fig. 1. The effect of load on SWR is less influential than the combined effect of load and L1 condition during the calculation of pooled error. This demonstrates that the sliding under SAE15W40 oil lubricant condition gives the optimal wear rate than the SAE 20W40 oil lubricant condition. The effect of sliding distance on SWR is less influential than the condition. The presence of hard crystal structure, acts as sharp asperities on the surface of the GCI specimen. Initially at short sliding distance, hard crystal which protrudes out of the GCI surface has suppressed this effect and reduced the contact area between the disc and the pin. This in turn increases the wear rate and the friction. As the sliding distance increases, these asperities get compacted due to the forced oil circulation between the sliding surfaces and become blunt, thereby increases the contact area between the sliding surfaces. This improves the wear rate, under long sliding distance. The SWR decreases with increase in sliding speed. When sliding at high speed, the material gets oxidized due to increase in temperature over the contact surface. This leads to the forming of Mechanically Mixed Layer (MML). As the speed increases, this MML will act as the lubricant between the two surfaces and thereby decreases the sliding wear rate.

Table 3: Response table for S/N ratio of SWR

Level	Load, L (N)	Sliding speed, S (m/s)	Sliding distance, D (m)	Condition
1	-7.7059	-0.6457	-10.0351	-26.3688
2	-18.3849	-18.0736	-11.5791	-0.5460
3	9.0900	-16.4615	-13.5667	-8.2660
Delta	10.6789	17.4279	3.5316	25.8229
Rank	3	2	4	1

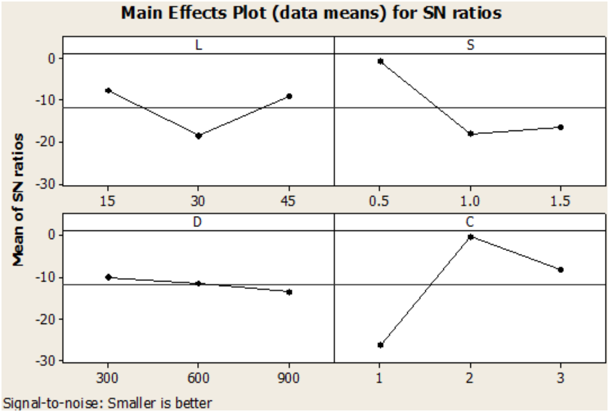

Fig. 1: Response graphs for S/N ratio of SWR

3.2. Analysis of Variance

The ANOVA of S/N data is carried out to identify the significant variables and to quantify their effects on the response characteristics. The most optimal settings of process variables in terms of mean response, SWR, are established through ANOVA as given in Table 4. Condition is the most contributing factor as 29.81% followed by the interaction of load and condition as shown highlighted in Table 4. Pooled error is 6.41%, which shows that the optimization holds good.

Table 4: ANOVA for SWR

Source of variation	DOF	Sum of squares (a)	Mean sum of squares (b)	F0 b/error	Contribution a/total
L	2	607	303.50	3.57	5.72%
S	2	1667.4	833.70	9.81	15.72%
C	2	3162.4	1581.20	18.61	**29.81%**
LS	4	765.1	191.28	2.25	7.21%
LD	4	1650.2	412.55	4.85	15.56%
LC	4	2073.4	518.35	6.10	**19.55%**
RE	8	679.9	84.99	-	6.41%
TOTAL	26	10607.5	-	-	100.00%

4. Confirmation Experiment

Experimental results are analyzed for identifying the optimum parameters. From Fig. 1 and response Table 3, the factors at level L1, S1, D1 and C2 that is corresponding to load 15 N, sliding speed 0.5 m/s, sliding distance 300 m and lubricant condition L1 are the optimum process parameters for obtaining minimum SWR. These optimum parameters are used to conduct the confirmation experiment and SWR prediction using Taguchi technique. The predicted and experimental values of SWR for these optimal sliding parameters for GCI are -13.525×10^{-5} mm^3/Nm and -9.312×10^{-5} mm^3/Nm respectively.

5. Conclusions

In this paper, sliding wear characteristics of GCI were evaluated experimentally using pin-on-disc wear test followed by DoE and Taguchi techniques. From the analysis, the following conclusions were drawn:

- Lubricant condition has the highest statistical influence on the wet sliding wear of the GCI (29.81%) followed by the interaction of load and condition (19.55%), sliding speed (15.72%) and the interaction of load with sliding distance (15.56%).
- The pooled error of the ANOVA is 6.41% for the factors showing 90% confidence level.

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