Data-based Probe for Bearing Balls using Design Expert with Biodegradable Media

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Abstract: This paper discusses about the lapping process for both metallic and non-metallic materials. The experiments were carried out based on the RSM design of experiments (DOE) approach to investigate the effect of their parameters on the lapping quality of ball bearing, for predicting the new results. This study explored the modification for fine finishing of bearing balls through Biodegradable medium (Aloe Vera) and silicon carbide (SiC) powder as an abrasive in addition of conventional oil-based media having an advantage like Antioxidant, antibacterial, non–toxic, good compression, and shear stresses. Spindle speed (rpm), Time (minutes), Force (N), Abrasive concentration were considered as the input process variables while the PISF, MRR and surface Roundness was considered as the process response. The result shows the most significant parameter for maximum PISF of 82.3%, 7.6 mg/min MRR and 9.05µm roundness was achieved with 672 rpm at 7.5 N forces, 37.5% abrasive concentration, 165 minutes' experimental run time was achieved.

Keywords: Biodegradable Material, Design Expert, Lapping Process, Steel Ball Finishing

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1 INTRODUCTION

Lapping is a fine finishing technology in which loose abrasives operate like cutting edges in between the two laps for a short time which do the necessary material removal [1]. The abrasive medium used in the lapping is one of the core part of lapping which contribute approx. 60% of the total finishing in this process [2]. Most of the lapping regulate with mechanical sanding type of abrasive, used to polishing the surface of the balls and many other applications by rubbing action [3]. In this process there are two lap one is fixed and another is movable in between these two laps addition of abrasive material is applied which is made up of different material. The unfinished parts are inserted inside these two laps which get contact with abrasive material "Fig. 1" [4].

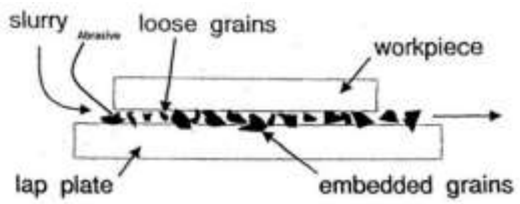

Fig. 1 Lapping plates.

By rubbing of movable lap there is material removal from the surface of unfinished parts due to the action of friction and rubbing between three-point zone namely, Stationary wall, Abrasive and Unfinished part material [5-6]. Sometimes we say it is hammering action between these three-point zone on one part. In lapping process some advantages related with dimensional accuracy or precise part is produced as compare to grinding and fabrication process, besides from these some more features in lapping process are [7]. "Table 1" represents the grading of lapping plates.

Table 1 Grading of lapping plates (Technique of Lapping A.W. Stahli AG)

Soft working plates	Paper, Cloths, Felt, Pitch, Plastic, Wood, Tin, Aluminum alloy etc.
Hard working plates	Cast-iron, Mild-steel, Soft, ceramics.
Hardened working plates	Hardened cast-iron, Hardened steel, Hard, ceramics etc. Up to 500HB
Multi-metal plates	Combination of 2-3 different metals or sintered metal powder

i) Loose abrasive is used in between the lap and workpiece.
ii) Generally, there is no any contact between lap and workpiece results less defects due to contact.
iii) There is a less change to produce Asperities over the surface of workpiece.

2 LITERATURE REVIEW

All Recently as well as a few years ago, independent studies were respectively conducted by King et al. in 1994 and Shah et al. in 2014 on the polishing and corrosion resistant technique using Aloe-Vera in lapping process. The Aloe-Vera composition of dentifrice was helpful in controlling plaque and plummeting the hazard of bacterial contamination [4]. They highlighted the bio-degradable material used for finishing and corrosion resistance manner which having good property regarding non-toxic, inexpensive and easily available [5]. Vegetable based cutting fluid during milling operations are also influence by Shankar et al. in 2017 in their study he uses four different vegetable cutting fluid like palm oil, coconut oil, soya bean oil, sunflower oil, and commercial cutting fluids was observed for milling operation of 7075-T6 hybrid aluminum metal matrix composite. The palm oil proved to be better cutting fluid medium than other vegetable based cutting fluids in terms of minimum cutting force requirement and minimum vibration [6].

Sadheghi et al. (2010) investigated the grinding of AISI 4140 hardened steel using the minimum quality vegetable lubrication technique. Sadheghi et al. studies about three different grinding fluid like vegetable oil, mineral oil and synthetic ester oils and compared them on the basis of grinding forces and surface finishing/quality properties suitable for MQL technique. The Vegetable oil had superior cooling property in case of grinding [7].

In lapping Surface finish has a vital influence on functional properties such as wear resistance and power loss due to friction. The important lapping process parameter which has been affecting the surface roughness are Voltage, mesh number, revolutions per minute (rpm), and weight percentage of abrasives [8].

The selection of abrasive material and its quantity is one of the important lapping parameters [9]. There are many different Abrasive materials are available in the market like Aluminum oxide, silicon oxide, silicon carbides etc. but SiC are one of the mostly applicable abrasive material in industrial, defense, electronics & electrical, aerospace, automobile and biomedical fields [10]. The prominent mechanical properties of SiC are high wear resistance, hardness, light weight, high durability, poor machinability, extreme brittleness, high rigidity, low density, high strength, excellent corrosion resistance, high intensity, high specific stiffness and high toughness [11-13].

The tool uses to optimized the various roughness process parameter is roughness surface methodology. Analysis of experimental data showed that percentage change in surface roughness (ΔRa) was highly influenced by mesh number followed by, rpm, weight percentage of abrasives, and voltage [8]. Other example of roughness

surface methodology process parameter technique in lapping is used by Kahraman F [14], Kaushik K A [15], Kim D J [16]. To attain the desired outcomes, it is important to select proper values for the lapping control parameters [17].
For industrial and manufacturing sectors the most prominent used balls are steel ball due to their following properties like, abrasion resistance, pitting corrosion resistance, impact strength etc. At low speed the surface roughness is minimum and the mesh size and abrasive quantity are kept constant [18]. The series of experiments are performed using design expert data [19] with parameter variation and calculating the material removal rate and surface roughness.

3 PROBLEM FORMULATION

The local bearing balls manufacturing industry Bhagwati Udyog use this traditional fine finishing process i.e. Lapping. the environmental conditions at the working place are very poor for human health. According to the literature and industrial experts there are prominent parameters which influences the finishing of the balls i.e. Spindle speed, Time for lapping, applied force and abrasive concentration. The major problems among these all parameters are the improper selection of raw material, improper design set-up, abrasive and abrasive medium. In the present study we have to modify the existing experimental set-up for fine finishing of ball and promote Bio-degradable material (Aloe-Vera) as an abrasive medium for improving the condition of working environment. In this study the effect of process parameters affecting the surface finishing, material removal rate and roundness of the balls will be analyzed using Design-expert solution software.

In the following sections, the literature review is brief. This is followed by the experimental Design and methodology. The detail methodology regarding process parameter optimization for lapping process. The present study develops the new design set-up of lapping process for industrial use and the effect of different lapping parameters on the working condition has been analyzed using Design-expert Solution. There would be a promotion of Bio-degradable material which acts as an Abrasive medium has to be use in Lapping process for eco-friendly new concept.

4 EXPERIMENTAL DESIGN AND METHODOLOGY

On the basis of literature reviewed and pilot investigations the following input process parameters and their respective range was selected. The objective of this study is to find the effect of input parameters on the output response parameters such as PISF, MRR and roundness. For the calculation of PISF initial and final surface roughness of the workpiece is required, which is measured using a surface roughness tester. And then the PISF is calculated using formula. Various Process parameters and their range are shown in “Table 2”; and “Table 3” shows the experimental design.

Table 2 Various Process parameters and their range

S. No.	Parameter	Units	Range
1	Speed	RPM	224-1528
2	Time	Minutes	15-65
3	Force	N	2.5-12.5
4	Abrasive conce.	%	12.5-62.5

Table 3 Experimental Design

		F1	F2	F3	F4	Resp. 1	Resp.2	Resp.3
Std	Run	A:SPE	B: TI	C: FO.	D: ABR.	MRR	PISF	RN
		RPM	MIN.	N	%	-	-	-
5	1	224	30	10	25	-	-	-
						-	-	-
25	2	672	75	7.5	37.5	-	-	-
						-	-	-
8	3	1120	120	10	25	-		
						-	-	-
26	4	672	75	7.5	37.5	-	-	-
						-	-	-
21	5	672	75	2.5	37.5	-	-	-
						-	-	-
4	6	1120	120	5	25	-	-	-
						-	-	-
11	7	224	120	5	50	-	-	-
						-	-	-
2	8	1120	30	5	25	-	-	-
						-	-	-
20	9	672	165	7.5	37.5	-	-	-

						-	-	-
6	10	1120	30	10	25	-	-	-
						-	-	-
10	11	1120	30	5	50	-	-	-
						-	-	-
19	12	672	15	7.5	37.5	-	-	-
						-	-	-
1	13	224	30	5	25	-	-	-
						-	-	-
27	14	672	75	7.5	37.5	-	-	-
						-	-	-
24	15	672	75	7.5	62.5	-	-	-
						-	-	-
7	16	224	120	10	25	-	-	-
						-	-	-
13	17	224	30	10	50	-	-	-
						-		
15	18	224	120	10	50	-	-	-

The new lapping design set-up was created for fine finishing of bearing steel ball which was replaced by old set-up of lapping created by Singh S &T and D in 2017. The new set-up was fulfilled the industrial requirement (Bhagwati udyog Pvt. Lmt.) under which the fine finishing of bearing steel balls is done using lapping process. For experimentation the set-up was created for 15 set of ball finishing. The experiment was designed using Response Surface Methodology technique which consists of 30 experiments. Each set of experiments contains 15 balls which are weighed using electronic weighing machine. The initial weight of each set of balls is recorded and initial surface roughness is so measured. Biodegradable Aloe Vera gel is prepared by peeling off the skin of the aloe Vera leaf and scratching the aloe Vera mash to make the gel for eco-friendly machining. At that point the gel is expelled of any polluting influences. The weight of the abrasive powder and aloe Vera gel is very important to measure as per requirement.

5 EXPERIMENTAL STUDY

Table 4 The experimental results

		F 1	F 2	F 3	F 4	Resp1	Resp 2	Resp 3
Std	Run	A: SPE	B: TIM	C: FOR	D: ABRASIVE	MRR	PISF	ROUNDNESS
		RPM	MIN.	N	%	mg/min	%	µm
5	1	224	30	10	25	1.9	54.65	12
25	2	672	75	7.5	37.5	4	74.72	14.52
8	3	1120	120	10	25	3.3	81.19	9.23
26	4	672	75	7.5	37.5	4	74.65	14.22
21	5	672	75	2.5	37.5	0.89	42.4	19.83
4	6	1120	120	5	25	3.01	78.02	10.05
11	7	224	120	5	50	2.9	75.56	16.25
2	8	1120	30	5	25	3.8	56.09	11.85
20	9	672	165	7.5	37.5	2.6	82.3	12.91
6	10	1120	30	10	25	1.63	50.8	10.3
10	11	1120	30	5	50	1.9	56.75	10.56
19	12	672	15	7.5	37.5	1.7	46.08	14.26
1	13	224	30	5	25	1.6	52.5	19.2
27	14	672	75	7.5	37.5	4	74.69	12.47
24	15	672	75	7.5	62.5	5.6	76.53	13.48

The experimental results, “Table 4”, are on the basis of input data i.e. Spindle speed in rpm, time required for lapping, abrasive concentration and force. The output parameters are Material removal rate, PISF and Roundness. RSM is utilized to investigate work of experiment response data.

6 ANALYSIS OF VARIANCE (ANOVA) FOR MRR

Collective Effect of Process Parameters on MRR, PISF:

6.1. Collective effect of Speed, abrasive concentration, time and force on MRR

This shows the relationship between Speed and force on MRR in "Fig. 2". When the force applied on the rough balls are low the material removal rate is also low and vice-versa.

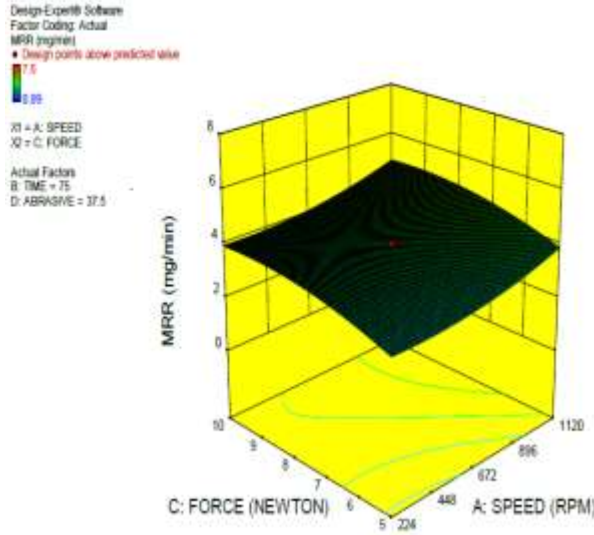

Fig. 2 Effects of force and Speed on MRR.

Table 5 The effects of input variables on output variables, time has high effect than speed, abrasive quantity, and force

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	43.61	14	3.12	3.21	0.0160	*Significant*
A-SPEED	5.84	1	5.84	6.02	0.0269	
B-TIME	6.92	1	6.92	7.13	0.0174	
C-FORCE	6.66	1	6.66	6.86	0.0193	
D-ABRASIVE	3.65	1	3.65	3.76	0.0715	
AB	0.065	1	0.065	0.067	0.7993	
AC	$2.500e^{-005}$	1	$2.500e^{-005}$	$2.576e^{-005}$	0.9960	
AD	0.026	1	0.026	0.026	0.8731	
BC	2.86	1	2.86	2.94	0.1068	
BD	0.065	1	`0.065	0.067	0.7993	
CD	1.20	1	1.20	1.24	0.2838	
A^2	2.71	1	2.71	2.79	0.1154	
B^2	12.17	1	12.17	12.54	0.0030	
C^2	3.95	1	3.95	4.07	0.0619	
D^2	0.35	1	0.35	0.37	0.5544	
Residual	14.56	15	0.97			
Lack of Fit	14.56	10	1.46			
Pure Error	0.000	5	0.000			
Cor Total	58.17	29				
Std. Dev.	0.99	R-Squared		0.7497		
Mean	3.27	Adj R-Squared		0.5162		
C.V. %	30.15	Pred R-Squared		-0.5531		
PRESS	90.35	Adeq Precision		7.054		
-2 Log Likelihood	63.44	BIC		114.46		
		AICc		127.73		

"Fig. 3" shows the relationship between abrasive concentration and speed on MRR. When the abrasive conc. is less, then lesser will be the material removal rate and vice-versa. "Fig. 4" shows the relationship between Time and Speed on the value of MRR. When the time of the finishing is less the value of the MRR is less and vice-versa. Similarly, when the speed of spindle is low the material removal rate is also low and vice-versa. When the force applied is lower MRR increases so in the case of abrasive concentration and then it increases slightly as the value of as the value of force is increased and then increases gradually towards the highest value of force. When the abrasive concentration is lower, then the MRR value is lower and it increases so in the case of speed and then it increases slightly as the value of abrasive concentration is increased. "Table 5" shows that input variables have high effects on output variables, and time with respect to the speed, abrasive quantity, and force.

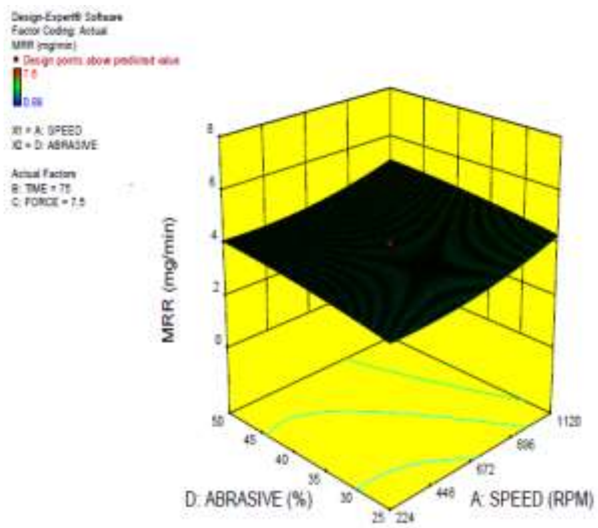

Fig. 3 Effects of abrasive and speed on MRR.

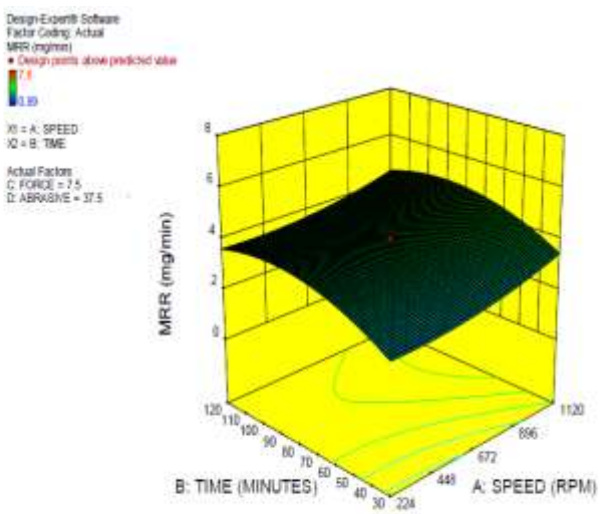

Fig. 4 Effects of Time and Speed on MRR.

Analysis of Variance (ANOVA) for PISF:

The "Table 6" shows the effect of input and output parameters on the PISF.

Table 6ANOVA for PISF

ANOVA for Response Surface Linear model						
Analysis of variance table						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2939.52	4	734.88	14.69	< 0.0001	Significant
A-SPEED	167.71	1	167.71	3.35	0.0791	
B-TIME	2319.83	1	2319.83	46.36	< 0.0001	
C-FORCE	310.54	1	310.54	6.21	0.0197	
D-ABRASIVE	142.74	1	142.74	2.85	0.1037	
Residual	1250.90	25	50.04			
Lack of Fit	1250.77	20	62.54	2440.37	< 0.0001	Significant
Pure Error	0.13	5	0.026			
Cor Total	4190.42	29				

Std. Dev.	7.07	R-Squared	0.7015
Mean	67.86	Adj R-Squared	0.6537
C.V. %	10.42	Pred R-Squared	0.5687
PRESS	1807.33	Adeq Precision	13.795
-2 Log Likelihood	197.05	BIC	214.05
		AICc	209.55

Factor	Coefficient Estimate	Standard Error	95% CI Low	95% CI High	VIF
Intercept	67.54	1.29	64.87	70.20	
A-SPEED	2.83	1.54	-0.35	6.01	1.00
B-TIME	10.32	1.52	7.20	13.45	1.00
C-FORCE	3.60	1.44	0.62	6.57	1.00
D-ABRASIVE	2.44	1.44	-0.54	5.41	1.00

Collective effect of Time and Speed on PISF:

This shows the collective effect of speed and time on Percentage Improvement in Surface Finish. When the speed of the rotation of the lap plate is increased the PISF also increases and vice-versa. The PISF increases rapidly with the increase in finishing time. (“Fig. 5”)

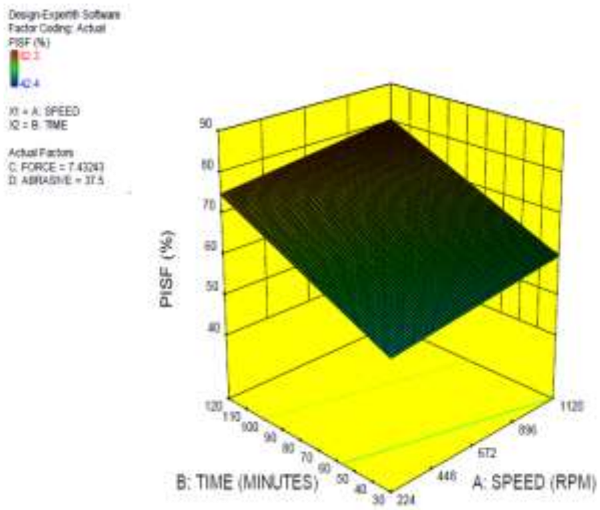

Fig. 5 Effects of Speed and Time on PISF.

Analysis of Variance (ANOVA) for Roundness

The “Table 7” shows the effect of input parameters on output parameters.

Table 7 ANOVA for Roundness

ANOVA for Response Surface Linear model						
Analysis of variance table						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	170.34	4	42.58	16.60	< 0.0001	Significant
A-SPEED	121.23	1	121.23	47.27	< 0.0001	
B-TIME	3.40	1	3.40	1.33	0.2603	
C-FORCE	45.65	1	45.65	17.80	0.0003	
D-ABRASIVE	0.054	1	0.054	0.021	0.8856	
Residual	64.12	25	2.56			
Lack of Fit	60.05	20	3.00	3.69	0.0764	Not Significant
Pure Error	4.07	5	0.81			
Cor Total	234.46	29				

Std. Dev.	1.60	R-Squared	0.7265
Mean	13.10	Adj R-Squared	0.6828
C.V. %	12.23	Pred R-Squared	0.5777
PRESS	99.00	Adeq Precision	13.750
-2 Log Likelihood	107.92	BIC	124.93
		AICc	120.42

Factor	Coefficient Estimate	Standard Error	95% CI Low	95% CI High	VIF
Intercept	13.11	0.29	12.50	13.71	
A-SPEED	-2.25	0.33	-2.92	-1.57	1.00
B-TIME	-0.40	0.34	-1.10	0.31	1.00
C-FORCE	-1.38	0.33	-2.05	-0.71	1.00
D-ABRASIVE	0.047	0.33	-0.63	0.72	1.00

A linear model is suggested for analysis of Roundness and cubic model is aliased. From Table 7 it is clear that for lack of fit tests linear model is suggested and cubic model is aliased. “Table 6” shows that model is significant for Roundness because p-value is less than 0.05. “Table 6” also shows the effects of input variables on output variables, speed has high effect than another three parameters.

7 CONCLUSION

The results of Biodegradable Aloe Vera gel with silicon carbides powder are tremendously great for fine finishing of mild-steel balls.

Following are the major conclusions of this study:

1. The process parameters were identified as

i) Resisting force

ii) Abrasive concentration.

iii) Rotational speed

iv) Finishing time

2. The maximum percentage of PISF is 82.3%, MRR 7.6 mg/min and roundness 9.05µm was achieved.

3. Most significant parameter for maximum PISF of 82.3% was achieved with 672 rpm, 7.5 N force, 37.5% abrasive concentration and 165 minutes’ experimental time.

4. Most significant parameter for Maximum Material removal rate of 7.6 mg/min is achieved with 1568 rpm, 75 minutes’ experimentation time, 37.5% abrasive and 7.5 N force.

5. The most prominent parameters under this study has been achieved 9.05µm of roundness with 1568 rpm, 75 minutes’ experimentation time, 37.5% abrasive and 7.5 N force.

7. The roundness of the balls was improved from 31.26 µm to 9.05 µm while the roundness of industrial sample was found out to be 16.13µm.

7 ABBREVIATIONS

MRR: Material Removal Rate

PISF: Percentage Improvement in Surface Finish

RSM: Response Surface Methodology

CCD: Central Composite Design

ANOVA: Analysis of Variance

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