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Analysis of Surface Roughness of Machined Surface of Powder Metallurgy Components

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Abstract - The surface roughness value (Ra) of sintered iron P/M components at different cutting speed has been investigated. Surface finish may also be critical for component assembly or system performance. Dimensional fit and mating surface interaction may require certain surface finish requirements to meet performance specifications. Experimental results of surface roughness (Ra) of P/M components at different cutting speed have been analyzed through the various process parameters during manufacturing using response surface model. It has been observed that the compaction pressure, sintering temperature and sintering time strongly influence the response variable, surface roughness. A second order response surface model (RSM) has been used to develop a predicting equation of surface roughness based on the data collected by a statistical design of experiments known as central composite design (CCD). The analysis of variance (ANOVA) shows that the observed data fits well into the assumed second order RSM model.

Keywords - Surface roughness, Sintered components, Hardness, Response surface, Central composite design, ANOVA.

1. INTRODUCTION

Powder Metallurgy Steel components often have to be machined after heat treatment in order to obtain the correct shape as well as the required surface finish. Surface quality influences characteristics such as fatigue strength, wear rate, corrosion resistance, etc.

The surface finish of a component may be critical for certain applications, affecting properties such as wear resistance, fatigue strength, and coefficient of friction.

The surface analysis is one of the most important factors of the metal machining process due to the tolerance and geometry requirements.[1-2] The characteristic of powder metallurgy (P/M) surface geometry is the main issue, because the porous structure affects the surface quality. The overall smoothness and surface reflectivity depend on density, tool finish, and secondary machining operations. A discontinuous cutting path and some vibration occur when cutting tool passes from the edge of one pore to that of another [3]. Experimental results of surface roughness (Ra) of P/M components at different cutting speed has been analyzed through the various process parameters using response surface model. It has been observed that the compaction pressure, sintering temperature and sintering time strongly influence the response variable, surface roughness. A second order response surface model (RSM) has been used to develop a predicting

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equation of surface roughness based on the data collected by a statistical design of experiments known as central composite design (CCD). The analysis of variance (ANOVA) shows that the observed data fits well into the assumed second order RSM model.

2. Experimental procedures

Kawasaki Steel Corporation Chiba Works, Chiba, Japan, supplied the iron Powder The relevant certification of chemical analysis and powder particle size distribution was performed by the same company and is presented in Table 1.

Table 1
Chemical Analysis of iron powder

C	Si	Mn	P	S	O	Total Fe
0.001	0.02	0.17 -	0.013	0.010	0.129	Balance

Powder Properties: Apparent Density (gm/cc): 2.94
Flow (s/50gm) : 24.7

Sieve Distribution:

Sieve Number	Size	Cumulative wt%
+ 100#	>150 um	8.5
+ 150#	>106 um	20.1
+ 200#	> 75 um	22.9
+ 250#	> 63 um	9.5
+ 325#	> 45 um	16.8
- 325#	<45 um	22.2

The iron powder was compacted in a closed cylindrical die using 120-Ton hydraulic press (make-Lawrence & Mayo) for green stage product (fig.1). During compaction, the die was lubricated with Z*n*-stearate. The sintering process was carried out in a tubular vacuum furnace of capacity 1450°C using argon as an inert atmosphere (fig.2). Since one of the major objectives of present investigations is to shade light on the hardness of the compacted sintered samples, 60 different P/M iron components (dia-25 mm) were produced according to design of experiment (DOE). Related surface roughness value of these samples were studied by Surftest SJ-301 (Mitutoyo) machine (fig.3)

against the variation of controllable process parameters like compaction, sintering time and sintering temperature. The results obtained through the experiments are given in Table 2 &. 3 and the available data have been analyzed by response surface method using Minitab software (version 14).

Fig.1.120 Ton. Hydraulic press.

Fig.2: Tubular Vacuum Furnace

Fig.3. Surface Roughness Surf test – SJ-301

3. Results and Discussions

Table 2 and Table 3 depict a variation of surface analysis against the process parameters.

Table 2

Actual and coded values of process parameters and symbols used.

Process parameters (Independent variables)	Symbols		Levels					
	Actual	Coded	Actual			Coded		
Compaction load (Ton)	z_1	x_1	17.66	20.075	26.4 9	–1	0	+1
Sintering temperature (° C)	z_2	x_2	975	1050	1125	–1	0	+1
Sintering time (hrs)	z_3	x_3	1	1.5	2	–1	0	+1

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Table 3.

Observed Surface roughness (Ra) – values for different settings of process parameters.

Sl. No.	Coded Value of Parameters			Actual Value of Parameters			Response variables Surface roughness Ra μm		
	x_1	x_2	x_3	Compact -ion Ton	Sintering Temp. °c	Sintering Time hour	R2 (@ cutting speed 18.37 m/min.	R2 (@ cutting speed 27.95m/min	R2 (@ cutting speed 4.24 m/min
1	-1	-1	-1	17.66	975	1	7.92	7.45	8.92
2	1	-1	-1	26.49	975	1	3.34	4.73	4.25
3	-1	1	-1	17.66	1125	1	5.71	7.16	6.86
4	1	1	-1	26.49	1125	1	2.31	2.75	2.29
5	-1	-1	1	17.66	975	2	6.31	6.88	8.57
6	1	-1	1	26.49	975	2	3.34	4.15	4.65
7	-1	1	1	17.66	1125	2	5.08	5.02	6.35
8	1	1	1	26.49	1125	2	3.25	4.40	5.65
9	-1.6818	0	0	14.6499	1050	1.5	7.08	7.22	8.59
10	1.68179	0	0	29.5001	1050	1.5	2.62	2.32	3.07
11	0	-1.6818	0	22.075	923.87	1.5	6.06	6.44	6.77
12	0	1.68179	0	22.075	1176.13	1.5	4.08	4.21	4.77
13	0	0	-1.6818	22.075	1050	0.6591	7.26	5.00	8.30
14	0	0	1.68179	22.075	1050	2.3409	5.40	4.98	6.52
15	0	0	0	22.075	1050	1.5	6.92	6.14	9.11
16	0	0	0	22.075	1050	1.5	6.75	4.78	7.73
17	0	0	0	22.075	1050	1.5	7.16	7.16	9.34
18	0	0	0	22.075	1050	1.5	7.56	7.92	6..32

19	0	0	0	22.075	1050	1.5	7.25	6.88	8.72
20	0	0	0	22.075	1050	1.5	6.88	7.02	7.24

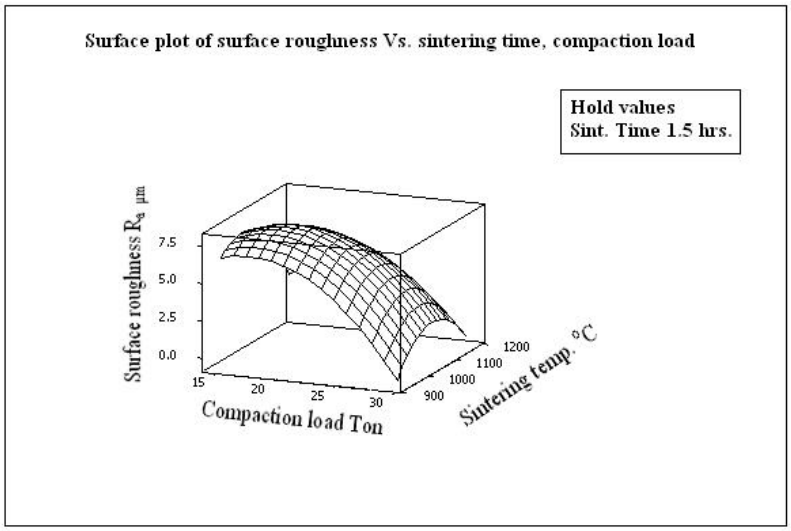

Fig. 4. Surface Plot of Surface roughness R_a µm (R1) vs Compaction load(X1), Sintering time (X3) Sintering temperature. X2

From the fig. 4. it is quite evident that with gradual increase of compaction load and sintering temperature, surface roughness initially increases up to a maximum value(R_a 7.92)and then decreases, following a non-linear function up to the experimental limit, sintering time being kept constant at the value of 1.5 hrs. Similar behavior has also observed on the surface roughness value with the variation of sintering time and sinter temperature, which is depicted in fig. 5. keeping the compaction load fixed at 22.08 Ton. Surface roughness attains a minimum value at high sintering temperature (1176^{0}C) over entire range of sintering time (0.659hr.to 2.34 hrs). The observed variation of surface roughness as manifested in figure 5 is nonlinear in nature. A change in surface roughness of the P/M components against sintering time and compaction load for a fixed sintering temperature of 1050^{0}C has shown in fig. 6. It is evident from the figure 6, that the

surface roughness of the P/M components under study shows an initial increase in surface roughness and then gradual decrease with increase in compaction load. This trend is observed for almost the entire range of sintering time. On the contrary at low compaction load (14.65 Ton) surface roughness starts with a high value(R_a µm 7.08) at low sintering time(0.659 hr.) and changes very little with increase in sintering time.

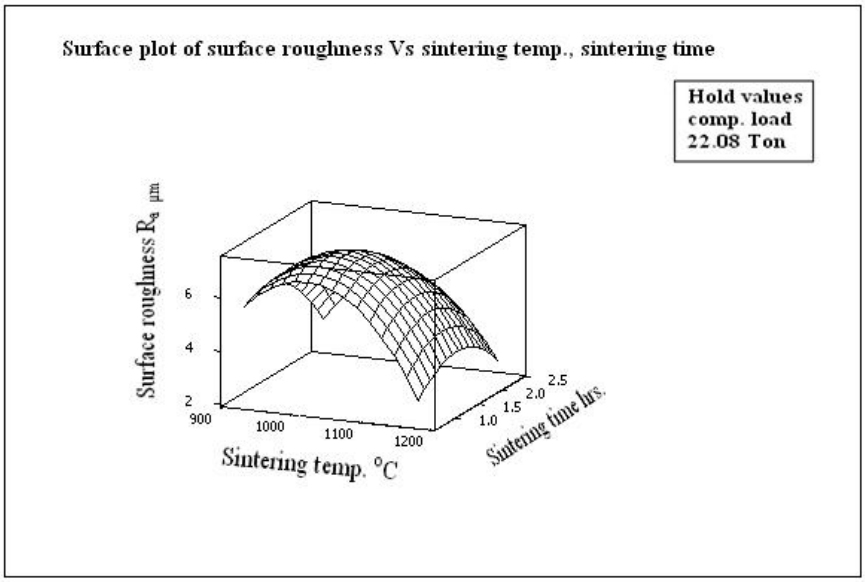

Fig.5 . Surface Plot of surface roughness R_a µm (R1) vs Sintering time (X3) Sintering temperature(X2).

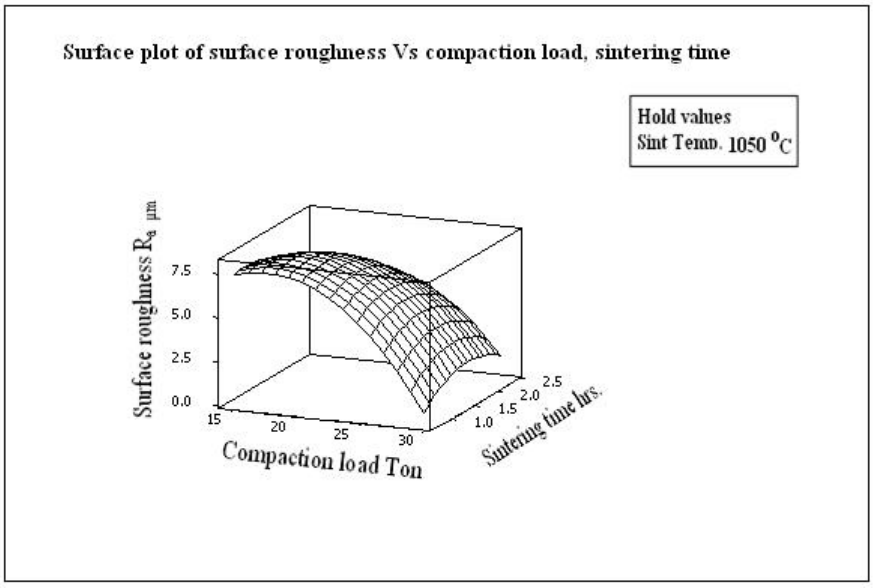

Fig. 6. Surface Plot of surface roughness R_a μm (R1) vs Compaction load (X1) Sintering time (X3).

From the fig. 5, it is evident that sintering time has very little effect on surface roughness. Variation of surface roughness against sintering temperature and compaction load is presented in fig.4. The figure exhibits an increasing tendency is due to change in sintering temperature from 975°C to 1176°C and compaction load from 14.65 Ton to 29.50 Ton at a fixed sintering time of 1.5 hrs. Identical nature of variation has noted in simultaneous increase of compaction load and sintering time has illustrated in fig. 6. In this fig., Compaction load has altered between 14.65 Ton to 29.50 Ton and sintering time has been changed between 0.6 to 2.3 hrs at invariant sintering temperature of 1050°C. The response variable i.e. surface roughness under consideration shows a non linear nature when it is plotted against sintering temperature and sintering time at a fixed compaction load of 22.08 Ton. (fig. 5). In this case, the range of variation of the parameters is similar to that of previous two cases. It is worth mentioning, in all the cases the hold values are mean value of the range of variation corresponding to each variable.

3.1. Statistical analysis

Table 4

Analysis of Variance for Surface roughness (Ra)

Source	DF	Seg SS	Adj SS	Adj MS	F	P
Regression	9	57.3536	57.3536	6.37262	30.01	0.000
Linear	3	34.3304	7.9507	2.65023	12.48	0.001
Square	3	20.8885	20.8885	6.96284	32.79	0.000
Interaction	3	2.1346	2.1346	0.71155	3.35	0.064
Residual Error	10	2.1235	2.1235	0.21235		
Lack-of-Fit	5	1.6719	1.6719	0.33437	3.7	0.089
Pure Error	5	0.4516	0.4516	0.09032		
Total	19	59.4771				

A significance test was conducted to examine the effect of different process parameters and their inter-actions terms on the said response. Table 5 shows the results of the significance test. The different terms used in Table 5 are as follows.

Table 5

Coefficients, standard errors, T statistics and p value for the response, Surface roughness (Ra).

Term	Coef	SE Coef	T	P
Constant	-129.949	27.8842	-4.660	0.001
X1	0.386	0.5963	0.648	0.532
X2	0.274	0.0471	5.821	0.000
X3	-4.222	5.0644	-0.834	0.424
X1*X1	-0.047	0.0062	-7.524	0.000
X2*X2	-0.000	0.0000	-6.884	0.000
X3*X3	-1.560	0.4855	-3.214	0.009
X1*X2	0.001	0.0005	2.187	0.054
X1*X3	0.150	0.0738	2.033	0.069
X2*X3	0.005	0.0043	1.066	0.311

R-Sq = 96.4%

From the results of ANOVA a mathematical model has been proposed for the evaluation of surface roughness of the powder metallurgy components. The proposed model is expressed as

$$SRccd = -129.949 + 0.386\ X_1 + 0.274\ X_2 - 4.222\ X_3 - 0.047\ X_1^2 - 1.560\ X_3^2 + 0.001\ X_1 X_2 + 0.150\ X_1 X_3 + 0.005\ X_2 X_3$$

Table 4 and Table 5 presents the ANOVA (Analysis of variances) and the significance test for the second order response surface equations, which quite clearly shows that second order response surface model fit well into the observed data. This is evident from the findings that co-efficient of determination (R^2) value is 96.4 %. Hence, it may be concluded that the prediction made by this developed model corroborates well with the experimentalobservations.

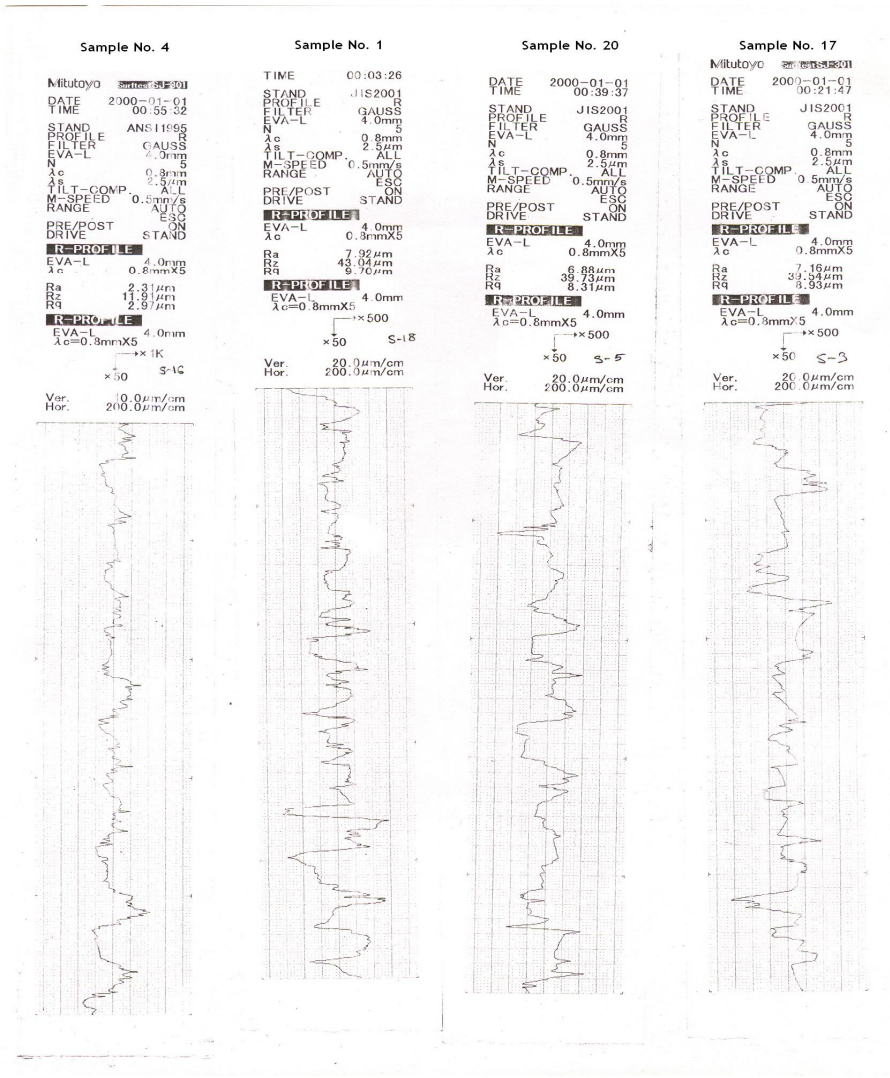

Fig.7. Comparison of surface roughness R_a of P/M samples

4. Conclusions

It is evident that the surface roughness of the P/M components under study shows an initial increase in surface roughness and then gradual decrease with increase in compaction load. This trend is observed for almost the entire range of sintering time. On the contrary at low compaction load (14.65 Ton) surface roughness starts with a high value ($R_{a\ \mu m}$ 7.08) at low sintering time (0.659 hr.) and changes very little with increase in sintering time. It is also evident that sintering time has very insignificant effect on surface roughness. The ANOVA (Analysis of variances) for the second order response surface equations, which quite clearly shows that second order response surface model fit well into the observed data. This is evident from the findings that co-efficient of determination (R^2) value is 96.4 %. Hence, it may be

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