STUDY OF PROCESS PARAMETERS AFFECTING 2D VIBRATION ASSISTED GASBAG POLISHING TECHNIQUE

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ABSTRACT:

Polishing processes are mainly concerned with surface finish. This study is concerned with the effect of various parameters on surface finish in vibration assisted gasbag polishing process.In the present work, vibration mechanism is designed to study and analyze effect of various parameters such as vibration frequency (10-20 Hz), pressure inside the gasbag (0.5-1.5bar), Wt. of SiC (10-30gm) and Wt. of iron (15-25gm); in what sense they affect the surface roughness and machining depth. The silicon carbide of 15μm size and iron powder are used as abrasives. The experiments are carried out on 45×45 mm workpiece of thickness 5 mm of the die steel materials. Surface finish achieved by using soft gasbag tool and abrasive powder.Taguchi orthogonal array L27 method is used to carry out the experiments. Statistical methods are used to establish the relationships between responses and the process parameters and Grey relation is used for optimization of parameters.

KEYWORDS: gasbag polishing, surface finish, machining depth, ANNOVA, Taguchi Method of DoE

INTRODUCTION:

The important attributes of any product are its shape, size, dimensional tolerances and surface integrity including surface finish. Surface finish is achieved from the last operation performed on the part, and this operation is known as finishing operation. In most of the cases, it also decides other surface characteristics of the machined part, for example, surface defects like micro cracks.[1] If finishing operation raises workpiece temperature more than the permissible one, it may lead to surface defects like micro cracks, thermal residual stresses and warping. Hence, the selection of a right kind of finishing process is very important. There are very wide range of trditional finishing processes are available such as grinding, honing, lapping, buffing and polishing. All these process have their inherent limitations. Nowadays, new advances in materials syntheses have enabled production of ultra-fine abrasives in the nanometer (nm) range. With such abrasives, it has become possible to achieve nanometer surface finish and dimensional tolerances. [2]

Gasbag polishing technique is one of the point of attraction for newly evolving technique as the finishing operations. Gasbag polishing technique is based on flexible polishing principle. The polishing head of tool has an inflated gasbag whose pressure can be controlled through throttle valves. Outside of the gasbag is the working face with the action of magnetic abrasive particles for polishing. These magnetic abrasive particles are controlled by the permanent magnet. The polishing head is circumrotating with high speed and rotation speed can be regulated. Moreover the flexibility of working face, equivalent area contacting with the curved surface and polishing force in radial direction can be controlled by adjusting the machining deepness and gasbag pressure. [3]

1.1 VIBRATION ASSISTED GASBAG POLISHING TECHNIQUE:

Mould is an important basis for the development of manufacturing industry. It has extensive application prospect in the fields of machinery, electronics, automobiles, light industry, building materials and national defense. Polishing is a significant process for mould manufacturing, thus plays an important role in ensuring the mould quality and improving its service life. 65%of the mould cavity is made up of curved surface, 40% of which is free-form surface. At present, polishing free-from surface mould is mainly manual with low production efficiency and unstable polishing quality. [4]

Polishing is the last procedure of mould manufacturing for obtaining certain level of form and texture by removing the traces and damaged layer caused by pre-matching before mould's application in industry. Polishing a mould which has free-form surface is a time-consuming and labor-intensive job, and requires great numbers of experienced experts and a considerable amount of high-precision skill. In addition, because of awful working condition caused by dust and noise, low efficiency of manual polishing and instable polishing quality, obtaining the required roughness and smoothness is costly. Polishing a mould having free form surface is time consuming and requires high precision skill. Most conventional rigid rubbing polishing methods are hard to restrain mechanical vibrations well and achieve a good compliance to the curved surface, thus results in lots of tiny potholes and relatively rough surface. Gasbag polishing technique is a new polishing method for free curved surface in order to reduce the polishing time and improve the polishing quality. It is applied on free-form mould surface for much higher local surface shape amendment precision and well-proportioned surface quality. It also has the advantages of large flexible contact area between the gasbag polishing tool and mould surface, controllable internal pressure and so on.[5] To enhance the surface finish an attempt is made to provide vibration of amplitude of 0.1 mm to the workpiece fixture.

Gasbag polishing system consists of following modules.[6]

- Gasbag polishing tool
- Gas source and pressure control system
- Rotation of polishing tool by AC motor and speed control system
- Magnetic abrasive particles
- Magnetic field generator or permanent magnet
- Vibrating Mechanism

1.2 MECHANISM OF MACHINING IN GASBAG POLISHING:

FORMATION OF MAGNETIC ABRASIVE BRUSH:

Figure 2.8 shows the configuration of magnetic abrasive brushes in which the magnetized abrasives stretch in a row from the pole to the material. In considering only the magnetic field, a continuous function, it is expected that the magnetized particles aggregate into bundles. However, the interaction of the magnetized particles must be taken into account.

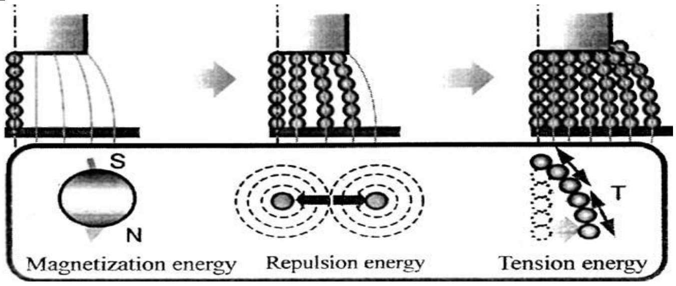


Figure 1. Configuration of magnetic abrasive brush [7]

Energy requirements in the production of magnetic abrasive brush using magnetic abrasives that are added little by little into the magnetic field are as follows,[7]

- Magnetization energy, required to magnetize the abrasives to form bundles.
- Repulsion energy, due to Faraday's effect causes the bundles to repel from each other.
- Tension energy, needed to counteract the curved bundles due to repelling particles.

Magnetic abrasive brush shows following characteristics,

- At an abrasive small volume, the diameter of each bundle is in the order of a few hundred micrometers that are separated from each other.
- With an increase of volume, the bundles get closer to other and the diameter of the bundles increase to several hundred micrometers, corresponding to several abrades.
- At large abrasive volume, the maximum diameter of a bundle does not increase but the number of bundles of several diameter increases. [7]

MECHANISM OF MACHINING:

Characteristics of magnetic abrasive polishing are summed as follows,

- A normal force and tangential forces, acting on the magnetic abrasive at brush edge, are generated by magnetic field.
- Each bundle is separated from each other.

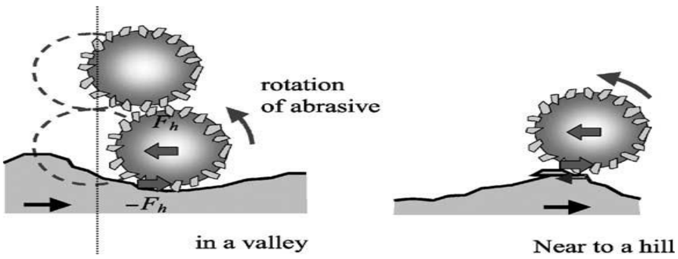


Figure. 2. Mechanism of machining [7]

By taking into account these characteristics, a polishing mechanism peculiar to this process can be explained, as shown in Figure 2[7]

1.3 ADVANTAGES OF VIBRATION ASSISTED GASBAG POLISHING TECHNIQUE:

- Gasbag polishing technique is more stable and effective because of cushioning of soft rubber gasbag compared to normal rigid rubbing polishing.
- It is applied on free-form mould surface for much higher local surface shape amendment precision and well-proportioned surface quality.
- It also has the advantages of large flexible contact area between the gasbag polishing tool and mould surface.

1.4 APPLICATIONS OF VIBRATION ASSISTED GASBAG POLISHING TECHNIQUE:

- Machinery industry
- Electronics industry
- Automobile industry
- Defense industry

LITERATURE SARVEY:

The concluding remarks from the literature survey is taken with respect to the following points,

2.1 FLEXIBLE CONTACT POLISHING (SOFT CONTACT POINT):

The contact between polishing tool and free-form surface is soft and the contact area is large, so it can obtain a smooth working contact face and high polishing efficiency satisfactorily. The control of stress and area of soft contact between polishing tool and free-form surface is attained through regulating the pressure of rubber gasbag. [4]

2.2 FORMATION OF MAGNETIC ABRASIVE BRUSH:

A magnetic abrasive brush was formed between a magnetic pole and a workpiece material which is expected to polish the material surface softly. [7]

2.3 CONCENTRATION:

To have deterministic machining behavior, the load, particle size and particle distribution must be well controlled within the machining zone between tool and work surface. The particle distribution is directly proportional to concentration of abrasive particles in magnetic abrasive particles.

2.4 EFFECT OF VIBRATION ON SURFACE ROUGHNESS:

Polishing quality obtained under vibration assistance is closely related to the mode of vibration. There are two modes of vibration. One mode is horizontal vibration on the X- or Y-axis of the workpiece, which serves to achieve self-sharpening or replacement of abrasive through back-and forth motion along X or Y direction. Although horizontal vibration can enhance machining precision, there is still room for improvement with regard to reduction in machining time. The other mode is vertical vibration on the Z-axis of the workpiece, which serves to increase the opportunity of impact between the steel particles and SiC abrasives within the working gap of the work piece and magnetic brush. Comparatively, horizontal vibration can achieve better surface quality than vertical vibration. [8]

In the X mode, x directional vibration offers the following advantages: (a) promotes relative motion of magnetic abrasives against the machined surface needed for the polishing operation by changing the value of relative velocity; (b) abrasives cutting edges may scratch the material in many directions in intermittent cutting mode, the cross-cutting marks are generated and stock removal per working distance is increased by the changing direction of relative velocity(c) promotes stirring effects. In the X mode, x directional vibration can help to promote the relative motion of magnetic abrasives against the machined surface and pressure distribution uniformity in the polishing zone, a smoother surface may be obtained. [9]

EXPERIMENTAL SETUP:

Keeping in view the influence of various process parameters of Vibration assisted Gasbag Polishing Technique; the experimental setup is performing polishing operation. The setup is developed with the help of existing drilling machine. It consists of assembly of tool holder and gasbag polishing tool, which is attached to the drilling machine spindle. It also consists of air compressor as the source of gas. Rotational speeds of spindle which are available with machine motor are 580 rpm, 820 rpm and 1140 rpm are used for experimentation and a constant speed is used for experimentation that is 820 rpm. Vibrating mechanism is clamped to the base of drilling machine.

Figure 3. Experimental setup for vibration assisted gasbag polishing process

Figure 3 shows the whole arrangement for the experimental setup for gasbag polishing process with the help of drilling machine. In this setup the workpiece is placed in work piece fixture of vibrating mechanism and it is mounted on the base table of drilling machine with the help of nut-bolts. Tool holder is attached to Drilling machine shaft. AC motor will give the rotational speed to the gasbag polishing tool.

The different components in the setup are:

- Vibrating mechanism
- Tool with tool holder
- Air compressor
- Pressure system
- DC power supply
-

3.1 MATERIALS:

WORKPIECE:

The workpiece materials chosen for the experimentation purpose is die steel. Material is selected on the basis application of the gasbag polishing process. As it can be widely used in mould polishing, therefore die steel is selected as a workpiece because it is most commonly used material for mould.

ABRASIVES:

Abrasives used are magnetic abrasive particles (MAPs). MAPs are made up of iron powder and abrasive powder. Abrasive powder used for experimentation is silicon carbide (SiC). The abrasives used are having size 15μm. These abrasives are mixed with iron powder with different combination by their weight.[10]

3.2 STEPS FOLLOWED WHILE WORKING ON EXPERIMENTAL SETUP:

- Clamp the Vibration mechanism with work piece to the work table of drilling machine.
- Set the rotational speed of tool by adjusting belt-pulley drive.
- Set the voltage of DC Power Supply for required speed of motor.
- Prepare the mixture of iron powder and silicon carbide abrasives with different concentration of by the weight.
- Spread this mixture onto the workpiece.
- Lower the drilling machine spindle in order to keep no gap between the tool and the work piece.
- Release the valve of air compressor reservoir to flow gas into gasbag till the required pressure is achieved.
- Start the motor of drilling machine spindle.
- Start the DC motor for vibration mechanism.
- Run it for 30 min.
- After specified time, stop both motors and remove the magnetic abrasive particles from workpiece as well as tool.
- Remove the workpiece from workpiece fixture.
- Measure the value of surface roughness of spot which is created by gasbag polishing process.

EXPERMIENTAL CONDITIONS:

Factors are selected from a cause and effect diagram in viewpoint to answer the question, of what factors may influence the surface roughness. Gasbag pressure, vibration applied to workpiece, wt. of SiC and wt. of iron are used for further experimentation. For an experiment, factor levels are kept at three level that is low, medium and high. The factors and their levels are shown in Table 1,

Table 6.1 Process factors and their levels

Levels	**Low (-1)**	**Medium (0)**	**High (+1)**
Vibration frequency (Hz)	10	15	20
Pressure in gasbag (bar)	0.5	1.0	1.5
Wt. of SiC (gm)	10	20	30
Wt. of iron (gm)	15	20	25

The vibration frequency, gasbag pressure, wt. of SiC and wt. of iron are the four factors and each factor has three levels considered for vibration assisted gasbag polishing process. In the present study, the interaction between the process parameters is neglected. To analyze effect of each parameter at all possible combinations the selected standard orthogonal array is L27 which has three level columns and twenty seven rows. Each process parameter can be assigned to column and twenty seven process parameter combinations are available in L27 orthogonal array matrix experiment. The experimentation is carried out under specified trial conditions. For each run responses of experiment i.e. surface roughness and machining depth are noted.

Table 1. L27 OA factor column assignment

Sr. No	**Vibration frequency(Hz)**	**Gasbag pressure(bar)**	**Wt. of Sic (gm)**	**Wt. of iron (gm)**
1	-1	-1	-1	-1
2	-1	-1	-1	-1
3	-1	-1	-1	-1
4	-1	0	0	0
5	-1	0	0	0
6	-1	0	0	0
7	-1	1	1	1
8	-1	1	1	1
9	-1	1	1	1
10	0	-1	0	1
11	0	-1	0	1
12	0	-1	0	1
13	0	0	1	-1
14	0	0	1	-1
15	0	0	1	-1
16	0	1	-1	0
17	0	1	-1	0
18	0	1	-1	0
19	1	-1	1	0
20	1	-1	1	0
21	1	-1	1	0
22	1	0	-1	1
23	1	0	-1	1
24	1	0	-1	1
25	1	1	0	-1
26	1	1	0	-1
27	1	1	0	-1

EXPERIMENTAL RESULTS AND ANALYSIS:

The spot is considered as output on the workpiece and is measured in terms of Surface roughness in Ra value in µm. The values in the Table 2 for Surface roughness are average of 5 values for each workpiece. These Ra values obtained in µm are measured by MitutoyoSurftest SZ201. The values in Table 2 for Machining depth indicating are measured with the NikkonDigimicro Digital comparator

Figure 3. Work surface of die steel workpiece

Table 2. Observational data for vibration assisted gasbag polishing process

Sr. No	Vibration frequency(Hz)	Gasbag pressure(bar)	Wt of Sic (gm)	Wt of iron (gm)	Surface roughness (µm)	Machining depth (mm)
1	-1	-1	-1	-1	0.8674	0.034
2	-1	-1	-1	-1	0.8698	0.032
3	-1	-1	-1	-1	0.8701	0.033
4	-1	0	0	0	0.8213	0.0687
5	-1	0	0	0	0.8195	0.0674
6	-1	0	0	0	0.81	0.067
7	-1	1	1	1	0.7845	0.069
8	-1	1	1	1	0.7806	0.068
9	-1	1	1	1	0.7789	0.0675
10	0	-1	0	1	0.8091	0.0811
11	0	-1	0	1	0.8001	0.0801
12	0	-1	0	1	0.7984	0.081
13	0	0	1	-1	0.721	0.071
14	0	0	1	-1	0.7124	0.07
15	0	0	1	-1	0.7014	0.069
16	0	1	-1	0	0.5897	0.088
17	0	1	-1	0	0.5878	0.089
18	0	1	-1	0	0.5804	0.089
19	1	-1	1	0	0.1542	0.075
20	1	-1	1	0	0.1518	0.069
21	1	-1	1	0	0.1497	0.065
22	1	0	-1	1	0.2541	0.099
23	1	0	-1	1	0.2534	0.0991
24	1	0	-1	1	0.2501	0.098
25	1	1	0	-1	0.1002	0.105
26	1	1	0	-1	0.098	0.11
27	1	1	0	-1	0.096	0.102

The regression statistics for above experimental parameters is as shown in Table 3,

Table 3. Regression analysis and ANOVA for surface roughness

Regression Statistics	
Multiple R	0.897254987
R Square	0.805066512
Adjusted R Square	0.769624059
Standard Error	0.166701993
Observations	27

Table 4. Regression analysis and ANOVA for surface roughness

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.3506	0.0320	-10.930	2.3344
Vibration frequency	-0.3614	0.0392	-9.1994	5.3870
Gasbag pressure	-0.0621	0.0392	-1.5817	0.1279
Wt. of SiC	-0.0304	0.0392	-0.7748	0.4466
Wt. of iron	0.0694	0.0392	1.7682	0.0908

Table 5. Regression analysis and ANOVA for machining depth

Regression Statistics	
Multiple R	0.912751026
R Square	0.833114435
Adjusted R Square	0.802771605
Standard Error	0.063033555
Observations	27

Table 4. Regression analysis and ANOVA for surface roughness

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.1397	0.0121	-93.951	3.7776E-30
Vibration frequency	0.1129	0.0148	7.6036	1.3577E-07
Gasbag pressure	0.0895	0.0148	6.0277	4.5678E-06
Wt. of SiC	0.0100	0.0148	0.6781	0.50476212
Wt. of iron	0.0579	0.0148	3.9008	0.00076783

R^2 is percentage of response variable variation that is explained by its relationship with one or more predictor variables. In general, the higher the R^2, the better the model fits your data. R^2 is always between 0 and 100%. It is also known as the coefficient of determination. Adjusted R^2 is percentage of response variable variation that is explained by its relationship with one or more predictor variables, adjusted for the number of predictors in the model. This adjustment is important because the R^2 for any model will always increase when a new term is added. The adjusted R^2 is a useful tool for comparing the explanatory power of models with different numbers of predictors. The adjusted R^2 will increase only if the new term improves the model more than would be expected by chance. It will decrease when a predictor improves the model less than expected by chance.

SE Coefficient is the standard deviation of the estimate of a regression coefficient. It measures how precisely the data can estimate the coefficient's unknown value. Its value is always positive, and smaller values indicate a more precise estimate. The standard error of a coefficient helps to determine whether the value of the coefficient is significantly different than zero – in other words, whether the predictor has a significant effect on the response [11], [12].

From the Table 3 and Table 5, the value of R^2 is greater than 70% which shows that experimentation is valid and all the above parameters are affecting the diameter of nanofibers [11]. The regression analysis is the statistical process for estimating relationship between the dependent and independent variables. Regression model helps to understand how typically the value of dependent variable changes with respect to the independent variable [11], [12]. To analyses the effect of individual parameter on the surface roughness and machining depth, the regression model can be given in equation form as follows,

Regression model for surface roughness is,

$Y = -0.364699301 - 0.3614655X1 - 0.06214981X2 - 0.0304428 X3 + 0.069477623 X4$

$SR = 10^{-0.364699301} V^{-0.3614655} P^{-0.06214981} S^{-0.0304428} I^{0.069477623}$

Regression model for machining depth is,

$Y = -1.1397 + 0.112969 X_1 + 0.089556X_2 + 0.010075 X_3 + 0.057956 X_4$

$MD = 0.072493655 V^{0.112969} P^{0.089556} S^{0.010075} I^{0.057956}$

Where, SR = Surface roughness (μm)

MD = Measured value of machining depth (in mm)

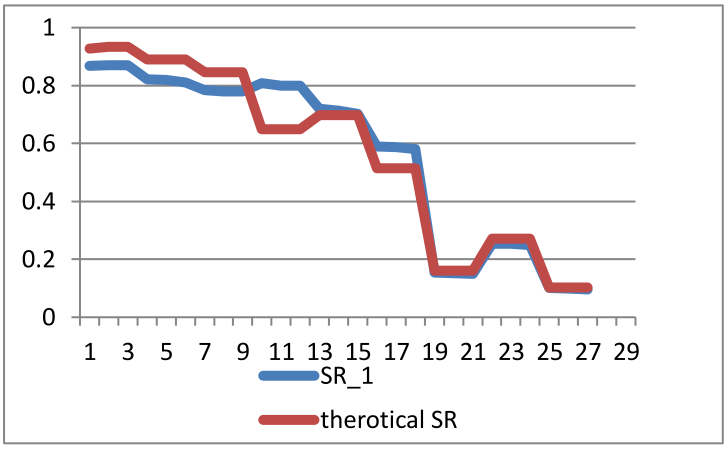
V = Vibrational Frequency (Hz)

P = Pressure in Gasbag (bar)

S = Wt. of SiC particles (gm)

I = Wt. of Iron particles (gm)

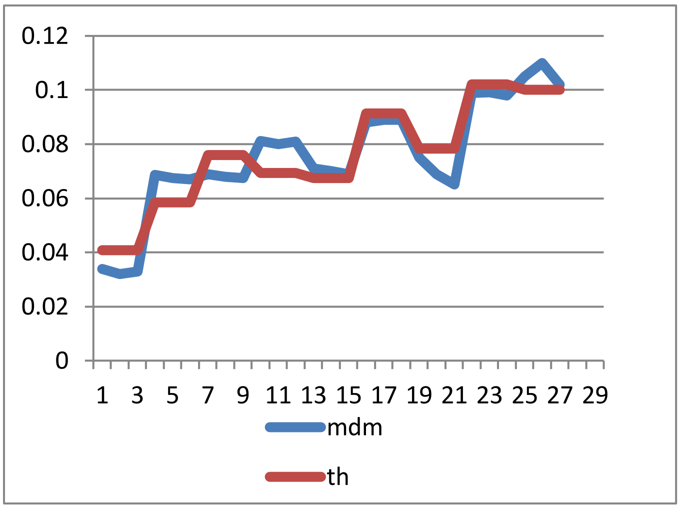
From the above equations, the % error between theoretical and actual surface roughness and machining depth were calculated as shown in below table. Further, graphs were plotted. Comparing the actual values and theoretical values mean % error which comes out is negligible so it is concluded that regression equation gives correct values for the considered inputs.



Graph 1 Difference between actual SR and Predicted SR from equation

Table 6. Comparison of actual and theoretical values

Sr. No.	Actual SR	Predicted SR from Equation	% Difference
1	0.8674	0.9274	-6.91722
2	0.8698	0.93375	-7.35226
3	0.8701	0.93375	-7.31525
4	0.8213	0.89	-8.36479
5	0.8195	0.89	-8.60281
6	0.81	0.89	-9.87654
7	0.7845	0.84625	-7.87126
8	0.7806	0.84625	-8.4102
9	0.7789	0.84625	-8.64681
10	0.8091	0.64825	19.88011
11	0.8001	0.64825	18.97888
12	0.7984	0.64825	18.80636
13	0.721	0.6987	3.092926
14	0.7124	0.6987	1.923077
15	0.7014	0.6987	0.384944
16	0.5897	0.5135	12.92182
17	0.5878	0.5135	12.64035
18	0.5804	0.5135	11.52653
19	0.1542	0.1598	-3.63165
20	0.1518	0.1598	-5.27009
21	0.1497	0.1598	-6.74683
22	0.2541	0.27175	-6.94608
23	0.2534	0.27175	-7.24152
24	0.2501	0.27175	-8.65654
25	0.1002	0.1027	-2.49501
26	0.098	0.1027	-4.79592
27	0.096	0.1027	-6.97917
Sum error			-25.9649
Average error %			-0.96166



Graph 2 Difference between actual MD and Predicted MD from equation

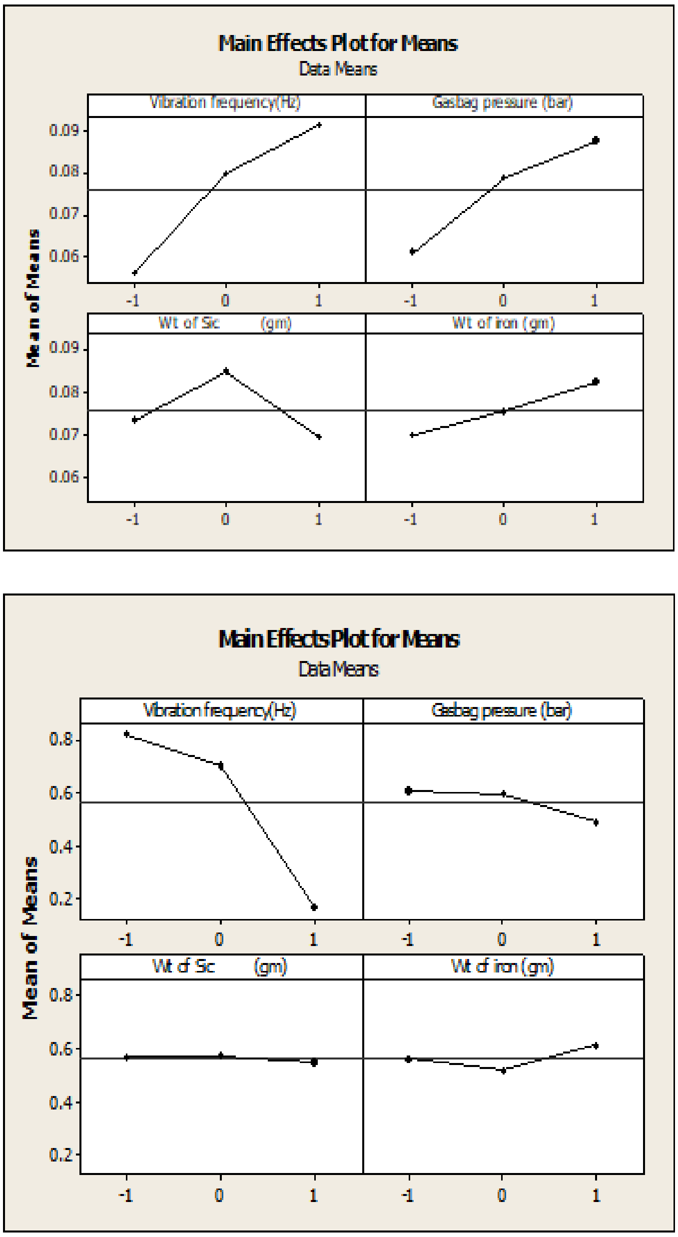
Table 7. Comparison of actual and theoretical values

Sr. No.	Actual MD	Predicted MD	% Difference
1	0.034	0.04081	-20.0294
2	0.032	0.04081	-27.5313
3	0.033	0.04081	-23.6667
4	0.0687	0.05842	14.96361
5	0.0674	0.05842	13.32344
6	0.067	0.05842	12.80597
7	0.069	0.07603	-10.1884
8	0.068	0.07603	-11.8088
9	0.0675	0.07603	-12.637
10	0.0811	0.06927	14.58693
11	0.0801	0.06927	13.5206
12	0.081	0.06927	14.48148
13	0.071	0.06738	5.098592
14	0.07	0.06738	3.742857
15	0.069	0.06738	2.347826
16	0.088	0.09126	-3.70455
17	0.089	0.09126	-2.53933
18	0.089	0.09126	-2.53933
19	0.075	0.07823	-4.30667
20	0.069	0.07823	-13.3768
21	0.065	0.07823	-20.3538
22	0.099	0.10211	-3.14141
23	0.0991	0.10211	-3.03734
24	0.098	0.10211	-4.19388
25	0.105	0.10022	4.552381
26	0.11	0.10022	8.890909
27	0.102	0.10022	1.745098
Sum error			-52.995
Average error %			-1.96278

The following figure shows, mean effect plots of input parameters for the surface roughness response and machining depth. From the mean effect plot we can say that, for the surface roughness, vibrating frequency is more affecting parameter as compare to remaining parameter whereas for getting the more effective machining depth, all parameters has to be considered.

Table 8. Concluding remarks from main effect plot

Sr. No.	Parameter	Effect on the surface roughness	Effect on the machining depth
1	Vibrating frequency(Hz)	Decreased	Increased
2	Gasbag pressure (bar)	Decreased	Increased
3	Wt. of Silicon powder (gm)	Almost same	Decreased
4	Wt. of Iron powder (gm)	Increased	Increased



Graphs 3. Mean effect plots

CONCLUSION:

Based on the results of the experiments and statistical analysis carried upon, the following general conclusions can be drawn,

- ✓ An approximate value of surface roughness (Ra) and machining depth in case of gasbag polishing process can be evaluated by the following equation,

Surface roughness,

$$SR = 10^{-0.364699301}\ V^{-0.3614655}\ P^{-0.06214981}\ S^{-0.0304428}\ I^{0.069477623}$$

Machinig depth,

$$MD = 0.072493655\ V^{0.112969}\ P^{0.089556}\ S^{0.010075}\ I^{0.057956}$$

- ✓ From the table 7, vibrating frequency, wt. of iron powder are the major parameters which are affecting the response parameters i.e. surface roughness and machining depth
- ✓ The optimum parameter for minimum surface roughness can be obtained by using following input parameters:

- Vibration frequency :20Hz
- Pressure in gasbag : 1.5 bar
- Wt. of SiC : 20gm
- Wt. of iron : 15 gm

- ✓ The optimum parameter for minimum surface roughness can be obtained by using following input parameters:

- Vibration frequency :20Hz
- Pressure in gasbag : 1.5 bar
- Wt. of SiC : 20gm
- Wt. of iron : 15 gm

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