ISSN: 0971-1260

Vol-22-Issue-17-September-2019

Experimental Investigation and Optimization of Internal Finishing of Steel Tubes Through Abrasive Finishing Using Electromagnets.

Avtar Singh, Swastik Pradhan and Loveleen Kumar Bhagi

School of Mechanical Engineering, Lovely Professional University, Punjab

E mail: avtar.e3@gmail.com

Abstract

Abrasive finishing using magnetic field has a plethora benefits for finishing the inner surface of cylindrical tubes and pipes. For small diameters and longer lengths of the pipes, where it is not possible for the tool to penetrate inside, MAF is the better alternative to improve inner surfaces of the tubes. Also MAF is more précised and accurate method as the force applied over the flexible brush is constant throughout the machining process.Controlled parameters are selected by using Taguchi approach and different sets of experiments are performed to search best combination of all variables for finishing the inner surface of SUS304 grade steel. By studying the literature review, it has been observed that the quantity of abrasives were taken not more than 15% till now, In this research work more emphasis is given on the increased amount of abrasives and their post effect on machining of SUS 304 grade steel tubes. Different grit sizes (150µm, 212µm, 300 µm and 425 µm) is used and MAF technique is applied at different RPMs (275, 400, 550, and 800) on the steel tubes for different time durations (30 min, 40 min, 50 min and 60 min) with controlled quantity of Al_2O_3 + Fe (4,6,8,10 grams) , where 70% of iron particles are mixed with 30% of abrasive particles.The outcome shows that higher machining duration for about 55 minutes is having more compatibilty with larger grit size, smaller quantities of abrasives and high RPMs.Further optimization is done to find out the effects of parameters on machining by using DFA. Percentage contribution of each factor is predicted by using ANOVA.

KEYWORDS- MAF (Magnetic abrasive finishing), Taguchi method, SUS304 steel, PISF-Percentage improvement in surface finish. DFA (Desirability function analysis), ANOVA.

ISSN: 0971-1260

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1. Introduction

High grade of surface finish on internal surfaces of cylindrical parts is needed in various applications ensuring safety of fluid passing through these tubes or pipes.
General cutting principle is applicable on abrasives selected for this process, abrasives being harder than work piece. A tangential force is developed against the inner surface of pipe which is responsible for machining of the inner surface. This tangential force against the inner surface forms microchips mostly in powdered form as the grit size is small. And after number of rpm's fine smooth inner surface will be obtained. For long pipes or tubes the position of either pipe or abrasives can be changed.
The study being done can be useful for number of mechanical industries producing fine tubes and pipes. Also the study may help the medical and chemical field as fine inner surface is required for medical syringes and other medical equipment where tubes are integral part of the equipment.
There are number of reasons for requirement of inner surface finish of tubes and pipes. The major one is contamination of gas and liquid flowing through the pipe or tube. The other reasons are as follows-

- Turbulence in the fluid flow
- Adherence of particulate matter to the surface
- Number of sites for microbial growth
- Cleaning and disinfection

Due to small irregularities over the inner surface of tubes and pipes the above mentioned problems may occur leads to conjunction of pipes and tubes with small diameters. So it becomes very necessary to obtain a smooth inner surface to avoid these problems. Turbulence in the fluid flow may affect the outlet pressure and velocity of the fluid decreasing overall efficiency of the system. A new problem may occur due to deposit of particulate matter of the impurities to the inner surface due to these irregularities. Due to these impurities deposited over the surface the chances of microbial growth increases, which may contaminate the fluid flowing through the pipe or tube. For smooth running of fluid inside a pipe regular cleaning is required if the surface is not smooth and chances of infections are there in case of medical equipment's. So for smooth fluid flow for a longer time a smooth inner surface is required.

Abrasive particles and Iron particles in appropriate ratio is used for machining of inner surface of pipes in the experiments. This mixture results in a brush type formation and act as a cutting toll, under the effect of a magnetic force towards the inner surface of pipe. Tangential force due to rotations results in microchip formation from the inner surface and leads for a smooth inner surface.

The present study is presented keeping in view the Knowledge developed after reading through the following literature review and survey. Mohammad Mosavat *et.al*[1] shows the coupled algorithm of SPH/FEM to obtain the surface finishing of silicon wafers using MAF process. It has been observed that micro fracture as well as micro cutting phenomenon happens and dependent on ploshing parametrs.Outcomes illustrate that material removal and surface roughness value increase with increase in rotational speed and with reducing machining gap. Vignesh V. Shanbhag *et.al*[4] develops an analytical method ton compute surface roughness with effect of quantity of active abrasives, RPMs, feed, flux density and size of abrasive particles. K. Zhou *et.al*[5] finds that the ultrasonic Maf has 40% more efficiency than normal MAF. Ultrasonic MAF faded out the milling texture from the surface, also initial micro cracks fully vanished out and surface stresses changed from residual tensile stress to residual compressive stress with a great decrement in stress from 280 Mpa to 20 Mpa. Xu Sun *et.al* [2] divides the EMAF process in two steps. In the first step EMAF is preformed followed by a single MAF step in second stage. Machinability of SUS304 is improved by development of layers(passive) by an electrolytic process.. Lida Heng *et.al[3]* reveals various working principles , processing parameters and various limitations for the MAF process in details. This study helps in finding an optimized experimental setup by reviewing all the possibilities in order to set magnets for MAF process. Gursharan Singh Gandhi *et.al* [6] Magnetic abrasive finishing method was implemented in this experimental study to improve the internal surface finish of the stainless steel SUS 304 tube. It was found that changing the operation parameters will affect the quality of work piece surface. R S Walia *et. al* [8] finds a hybrid machining method in order to improve performance of MAF technique by using a centrifugal force generating rod, new surfaces are generated by erosion from multiple attacks by abrasives. Vasistha Ganguly *et.al* [7] analyse the effects of changing polishing parameters on forces acting during polishing, With change in working gap polishing forces varies considerably and with iron particles size surface roughness have a great decrement and 2-3 nm surface roughness achieved. Mithlesh Sharma *et. Al* [9] uses magnetic abrasives sintered in a sintering machine, different materials were chosen with different variable parameters with the aim to find maximum efficiency in terms of MRR(material removal rate).Ikko lhara *et. al* [9] studied on dairy industry with an objective to find effect of surface finish on clean ability of milk carrying pipes to remove fouling deposits using magnetic abrasive finishing. Swastik Pardhan *et.al* [10] uses desirability function analysis to optimize machining parameters for the desired values as outcomes.

2. Experimental setup

The experimental setup contains electromagnets installed at right angle mounted over the carriage of a lathe machine. Work piece is tightly held in the chuck of a lathe machine and a magnetic flux is provided in the vicinity of the rotating work piece. Controlled quantities of abrasive powder mixture (Al_2O_3+Fe) are filled inside the work piece to accomplish magnetic abrasive finishing as shown in figure 1.

Major parts of the experimentation include machining setup and Taguchi approach to find best possible combination of set of experiments. As there are four different parameters that have to be considered while performing experiments, these four parameters further have four different levels. This data combination gives total a number of 256 experiments. Performing such a large number of experiments may lead towards setup failure and also consumes a lot of time. So to optimize the process, Taguchi method was used to obtain best possible 16 combinations of the parameters with different levels. Before performing these 16 experiments, a trial experiment was performed and many such things were found that helps in deciding the exact working conditions.

Also to obtain different grit sizes of the iron particles, Sieve tester apparatus has been used to obtain four different mesh numbers of the iron particles. To check the surface roughness before and after each experiment, surface roughness tester apparatus has also been used.

ISSN: 0971-1260

Vol-22-Issue-17-September-2019

Figure 1. Experimental setup over the lathe machine

3. Results And Discussions

Set of experiments are performed on the inner surface of the steel tubes and results after machining is obtained and the result is presented in the most understandable manner.

Machining of 8 different specimens were done one by one from both the ends comprising total of 16 set of experiments using magnetic abrasive finishing technique under controlled parameters . After machining, PISF is to be calculated as,

$$PISF = \frac{\text{INITIAL VALUE} - \text{FINAL VALUE}}{\text{INITIAL VALUE}} * 100$$

Initial surface roughness of the specimen measured by cleaning the inner surface of the tube and it comes around **1.04 Ra**. Two vertical and two horizontal readings are taken to ensure uniform finishing of the inner surface, so four different values were taken throughout the inner surface, to obtain the precise roughness value of the specimen. Each experiment performed by taking care of all the four parameters designed by Taguchi method. Results are obtained for each experiment by measuring the surface roughness and PISF is calculated.

On the basis of Taguchi method employed, following outcome is observed-

EXPERIMENT NUMBER	Machining Duration(minutes)	grit size(µm)	RPM	quantity(grams)
1	30	150	275	4
2	30	212	400	6
3	30	300	550	8
4	30	425	800	10
5	40	150	400	8
6	40	212	275	10
7	40	300	800	4
8	40	425	550	6
9	50	150	550	10
10	50	212	800	8
11	50	300	275	6
12	50	425	400	4
13	60	150	800	6

14	60	212	550	4
15	60	300	400	10
16	60	425	275	8

Table 1 machining parameters obtained by Taguchi method

3.1 Desirability function analysis with Taguchi method

DFA approach is employed to find out best set of parameters in order to reach optimization for the given set of experiments. Desirability function converts all he output responses into a free scale value know as desirability. Higher composite desirability value confirms the optimal parameters. Following steps are used to carry out DFA.

Step 1- Compute individual desirability index.

Step 2- Compute the composite desirability.

Step 3- ANOVA is used to find out most influencing parameter in MAF.

Step 4- The optimal parameters setting available from analysis are used to find out the composite desirability value.

This multi response optimization technique is based on three criteria, the nominal the best, the smaller the better and the larger the better. Individual desirability and composite desirability for horizontal and vertical values of surface roughness is shown in Table 2. Based on composite desirability it has been found that experiment number 3 shows maximum desirability index and found to be most optimized combination among all parameters. Following formulas have been used to find individual and composite desirability.

$$d_i = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{1}$$

Where, d_i represents the individual desirability index

$$d_g = (d_{\grave{}}^{w1} \times d_{\grave{}}^{w2} \times \ldots\ldots\ldots \times d_{\grave{}}^{wi})^{\frac{1}{w}} \tag{2}$$

Where, d_g is the overall desirability grade, w_i represents the individual desirability index.

Table 2. Calculation of DFA

 ISSN: 0971-1260

Vol-22-Issue-17-September-2019

Sl No	individual desirabiltiy index (di)		dG	Rank
	RA Horizontal	RAVertical		
1	0.283	0.690	0.665	7
2	1.000	0.381	0.786	5
3	0.792	0.976	0.938	1
4	0.887	0.690	0.885	2
5	0.264	0.571	0.623	10
6	0.340	1.000	0.763	6
7	0.396	0.429	0.642	9
8	0.698	0.690	0.833	3
9	0.094	0.576	0.383	15
10	0.094	0.238	0.387	13
11	0.001	0.357	0.001	16
12	0.377	0.476	0.651	8
13	0.057	0.071	0.252	14
14	0.283	0.310	0.544	11
15	0.340	0.214	0.519	12
16	0.547	0.738	0.797	4

Further ANOVA is applied to find out the impact of each parameter on machining and it has been observed that machining duration has the greatest impact on machining in MAF among all other parameters. Table 3 represents the percentage contribution of all the parameters in machining. Coefficient of determination value obtained is 87.90%

Table 4 represents ranking of various parameters as machining duration have greater impact and RPMs with lowest impact on machining in MAF process.

Table 3. Analysis of Variance for SN ratios

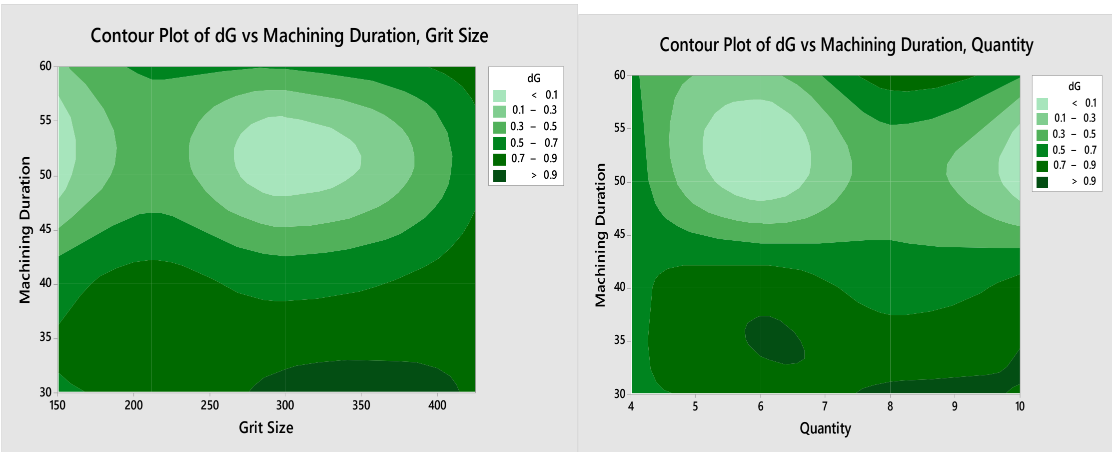
Source	DF	Seq SS	Adj SS	Adj MS	F	Percentage contribution
Machining Duration	3	4680	4680	1560.1	3.78	45.75
Grit Size	3	1692	1692	563.9	1.37	16.54
RPM	3	1143	1143	380.9	0.92	11.17
Quantity	3	1478	1478	492.5	1.19	14.45
Residual Error	3	1238	1238	412.8		
Total	15	10230				

Table 4. Response of mean

Level	Machining duration (min)	Grit Size (Micron)	RPM (RPM)	Quantity (Grams)
1	0.8182	0.3851	0.5564	0.6255

2	0.7155	0.62	0.6449	0.4678
3	0.2596	0.5248	0.5788	0.6864
4	0.5282	0.7915	0.5415	0.5419
Delta	0.5586	0.4064	0.1034	0.2186
Rank	1	2	4	3

Further, from the contour plots presented here graphical presentation is shown to elaborate the effect of machining duration with varying grit size, RPM and quantity of abrasive particles. It has been observed that with variation of one parameter over the other affects the response parameter. From figure 2(a) it is observed that grit size of 300 microns suits best with machining duration of 55 minutes.



(a) (b)

Figure 2: (a) Machining duration VS Grit size(b) Machining duration VS Quantity

Smaller quanties of abrasive (6 gms) and high RPMs of about 600 RPMs shows better results with about 55 minutes of machining time as shown in figure 2(b) and figure 3.

It is observed from the graphs that higher machining duration for about 55 minutes is having more compatibilty with larger grit size, smaller quantities of abrasives and high RPMs.

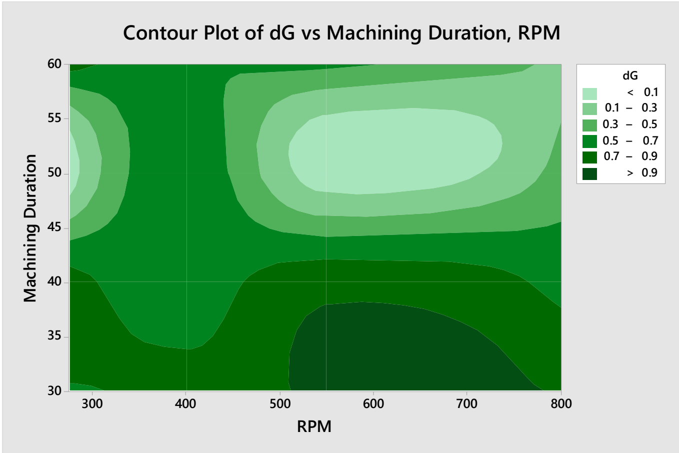


Figure 3: Machining Duration VS RPM

4. Conclusion

Subsequent compiling the data of all experimentations done using the Taguchi methodology and further, analysis concluded that the desirable outcomes were due to the following reasons:

1. The study shows the impact of Al_2O_3 as abrasive material on the inner surface of SUS 304 steel tubes using MAF technique and it includes the details of the mechanisms involved in MAF technique.
2. Results shows that higher machining duration for about 55 minutes is having more compatibilty with larger grit size, smaller quantities of abrasives and high RPMs
3. It is observed that the parameters chosen for the research have great impact on PISF, interrelations between machining duration and RPM, machining duration and grit size, machining duration and quantity of Al_2O_3+Fe particle mixture significantly affect the PISF.

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