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Parametric Investigations into Internal Surface Modification of Brass Tubes with Alternating Magnetic Field

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Abstract

The final finish operations have great significance in an overall manufacturing cycle of a product. The surface finishing and modification of surfaces have been the vital requirements of most of the products. The processes like shot peening, shot blasting, abrasive finishing and super finishing are being largely employed for such requirements. While final finishing of flat and outside surfaces are relatively easy and well established, the internal surfaces such as those of pipes is not so simple. In this paper, the application of low frequency alternative magnetic field has been explored for imparting surface modification including surface on the internal cylindrical surface. The cold drawn SUS304 stainless steel (SS) pins have been used as micro tools. The interaction of vibrating SS pins (due to AC magnetic field) with internal surface of rotating pipe has resulted in micro indentation of surface thereby improving surface characteristics. An experimental setup has been developed to investigate the effect of major process parameters on the percentage improvement in surface finish and surface hardness. Response Surface Methodology has been employed to design the experiment for demonstrating the effect of various process parameters on the surface finish and hardness of the processed surface. It is observed that SUS304 stainless steel pins are capable of improving the surface characteristics like surface finish and surface hardness in the internal surface of brass tube.

Keywords: Surface Modification, peening, AC magnetic field, Final finish operation, Surface hardness

1 Introduction

Surface modification is the physical transformation of a characteristic of a surface to improve its surface properties such as its roughness, hardness or fatigue strength etc. Surface characteristics can be

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modified by inducing compressive residual stresses on work surfaces. Shot peening or modified shot peening processes such as water jet peening, cavitation peening and ultrasonic shot peening are widely used to induce compressive residual stresses on the surface to improve the surface integrity and fatigue strength. But these processes are difficult to apply on internal surfaces such as high pressure liquid pipes and pressure fuel pipes. Surface characteristics of external as well as internal surface can be improved by a recently developed surface finishing/modification process called Magnetic Abrasive Finishing (MAF). In MAF, workpiece is held between the two poles of magnet. Magnetic Abrasive Particles (MAPs) used as finishing tool, are filled between the workpiece and the magnetic poles. The magnetic abrasive particles joined to each other along the lines of magnetic force and form a Flexible Magnetic Abrasive Brush. The flexible magnetic abrasive brush acts as a multi-point cutting tool for finishing process. The vibratory, rotary & axial motion is imparted to the workpiece to improve the performance of finishing operation. In magnetic abrasive finishing, magnetic field can be induced in three different ways i.e. by permanent magnets, direct current or by alternating current. At Initial stages, MAF was used only for finishing of flat surfaces but later this process was successfully utilized for finishing of external as well as internal surfaces (Shinmura, et al., 1985), (Shinmura and Aizawa, 1989). Magnetic abrasive finishing of internal surfaces is always a bit difficult task to deal with. Most of the researchers have utilized permanent magnets to induce magnetic field for internal surface finishing of metallic components made up of ferrous material like steel (Shinmura and Yamaguchi, 1995), (Yamaguchi and Shinmura, 2000) and non ferrous materials like aluminum alloy tubes (Yamaguchi and Shinmura, 2004), (Wang and Hu, 2005). Very small diameter SUS304 stainless steel capillary tubes were also successfully finished by MAF with permanent magnets (Yamaguchi and Shinmura, 2000), (Yamaguchi, et al., 2007), (Kang, et al., 2012), (Kang and Yamaguchi, 2012). Direct current is also successfully utilized by various researchers to induce magnetic field during magnetic abrasive finishing process for internal surface finishing of tubes (Yamaguchi, et al., 1996), (Kim, et al., 1997), (Yamaguchi and Shinmura, 1999), (Kim 2003). Only few researchers have utilized alternating current for internal surface finishing of tubes (Yamaguchi, et al., 2003), (Kumar, et al., 2012).

In a recent development in MAF with alternating current, Yamaguchi (Yamaguchi, et al., 2003) used cold drawn SUS304 stainless steel pins for surface modification of steel surface. It was concluded that surface characteristics can be modified by these pins if used in alternating magnetic field. Cold drawn SUS 304 stainless steel pins were also proved to be a good magnetic tool to induce compressive residual stresses and to improve microstructure of internal surface of brass tubes in magnetic abrasive finishing with alternating current (Kumar, et al., 2012). In present work, alternating magnetic field has been used for internal surface modification of brass tubes with the help of SUS304 stainless steel pin. The brass workpiece is chosen as it is non magnetic in nature. Moreover, due to its favorable mechanical/machining properties it has several applications in automotive, sanitary, and food processing industries. The aim of the present research is to investigate the effect of process parameters on surface characteristics like surface finish as well as surface hardness so as to explore the application of concept for internal surface finishing and modification of tubes.

2 Experimental Setup

An indigenous experimental setup has been designed and developed to carry out the detailed investigation. As shown in Figure 1, there are two coils which are in parallel circuit to each other. Cores in the coils facing each other act as N-S pole in alternating magnetic area. The gap between the poles can be varied axially to achieve the desired magnetic field. Work piece is to be kept in between the two poles. Magnetic coils are made up of 19 SWG copper wire (3000 Turns) wound around the core which is made up of SS400 rolled steel. The electromagnet is capable to induce alternating magnetic field up to 0.7 Tesla. Constant voltage is supplied through the coils. Variable frequency circuit has been designed to vary the frequency from 0.5 Hz to 55 Hz. Experimental set up has been installed on a lathe machine in such a way that the centre of lathe chucks coincide with the centre of the magnetic coils.

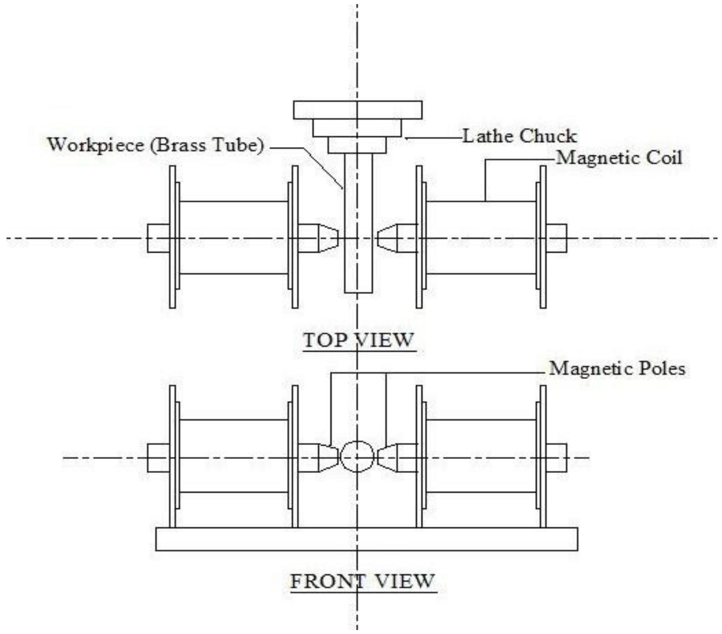


Figure 1: Schematic Diagram of Experimental Setup

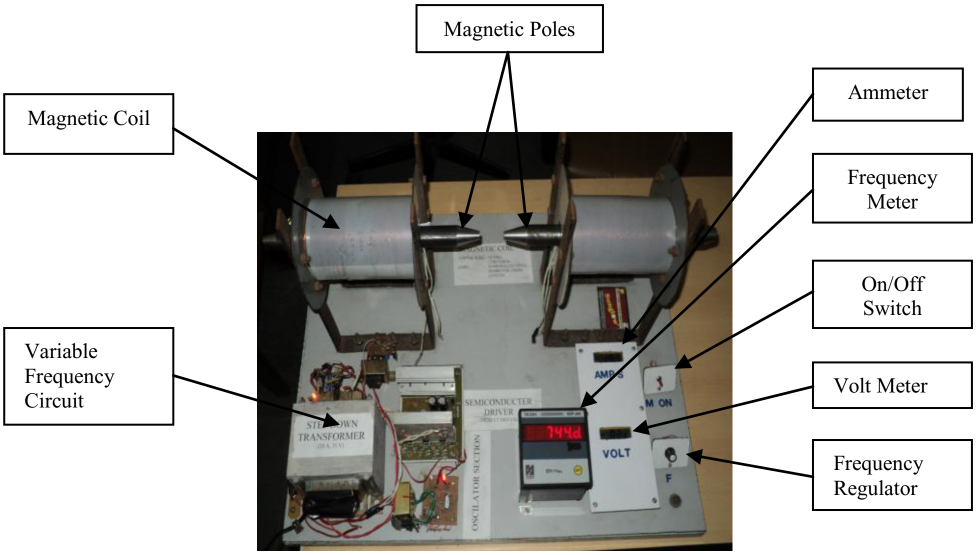


Figure 2: Photographic View of Experimental Setup

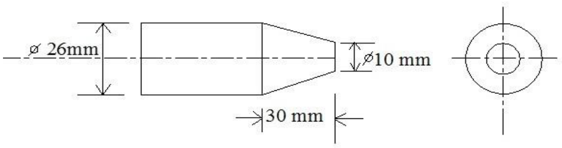
3 Experimentation

For internal surface finishing and modification of brass tube, there are many process parameters like work material, processing time, pole-work gap, shape of pole, geometry of pins, quantity of pins, vibrating frequency, magnetic flux density and surface rotational speed etc. which can affect the surface characteristics. On the basis of preliminary experimentations and process capabilities, four major process parameters: processing time, pole-work gap, vibrating frequency surface rotational speed and their range had been selected for final experimentation (Table 1).

Table 1: Experimental Conditions

Workpiece	Brass tubes (Ø25 x Ø22 x 100mm)
Tool	SUS304 Stainless steel Cold formed Pins (Ø2 × 6 mm).
Electro- magnetic pole	Core - SS400 Rolled Steel (Ø26 × 150 mm), Copper wire (19 SWG), 3000 Turns
AC Power	2 A, 25 V
Process Parameters	Processing Time : 30-150 min. Pole-Surface gap : 1-5 mm Vibrating Frequency : 3-7 Hz Surface Rotational speed : 70-340 RPM

Table 2: Coded and Real Level of Independent Variables

Parameters	**Symbol**	**Levels**				
		-2	**-1**	**0**	**1**	**2**
1.Processing Time (Mins)	A	30	60	90	120	150
2.Pole-Work gap (mm)	B	1	2	3	4	5
3.Vibrating Frequency (Hz)	C	3	4	5	6	7
4.Surface Rotational speed(rpm)	D	70	138	205	273	340
Constant Parameters						
Workpiece Material	Brass					
Quantity of Magnetic Tool (SS Pins)	4 gm					
Geometry of Magnetic Tool (SS Pins)	Ø2 × 6 mm					
Dimensions of Workpiece	Ø25 x Ø22 x 100 mm					
Shape of Pole						
Response Characteristics 1. Percentage Improvement in Surface Finish (PISF) 2. Percentage Improvement in Surface Hardness (PISH)						

Bored and finished brass tubes having dimensions Ø25 x Ø22 x 100 mm has been selected for final experimentation. Final experiments have to be conducted on a precision lathe machine. Stainless steel pins are inserted into the work piece. When the circuit is energized, it will produce alternating magnetic field which influence the position of magnetic pins. Both ends of workpiece are duly plugged to ensure the pin movement in the specific region. Work piece is held in precision lathe chuck and can be rotated according to experimentation plan.

Magnetic field between the poles can be adjusted by varying the distance between the poles. Magnetic coils are capable of generating the magnetic field up to 0.7 Tesla. The minimum and maximum values of four process parameters are determined from a series of trials with a pin of length (Ø2 × 6 mm). Table 1 shows the detailed experimental conditions.

In present research work, Response Surface Methodology (RSM) has been used to design the experiments. Four independent variables which show considerable effect on response characteristics were selected and could be varied up to five levels (Table 2). Central composite design was used to design the experiment. After deciding the parameter range, final experiments have been designed using ANOVAs design of experiment approach. According to ANOVAs design of experiment approach, experimentation plan has been decided as per Table 3.

Table 3: Experimentation Plan

Exp. No.	Order of Exp.	Processing Time (Mins)	Pole-Work Gap (mm)	Vibrating Frequency (Hz)	Surface Rotational Speed (RPM)
1	12	-1	-1	-1	-1
2	17	1	-1	-1	-1
3	26	-1	1	-1	-1
4	23	1	1	-1	-1
5	2	-1	-1	1	-1
6	27	1	-1	1	-1
7	11	-1	1	1	-1
8	30	1	1	1	-1
9	18	-1	-1	-1	1
10	28	1	-1	-1	1
11	19	-1	1	-1	1
12	7	1	1	-1	1
13	25	-1	-1	1	1
14	29	1	-1	1	1
15	13	-1	1	1	1
16	1	1	1	1	1
17	5	-2	0	0	0
18	14	2	0	0	0
19	8	0	-2	0	0
20	9	0	2	0	0
21	3	0	0	-2	0
22	24	0	0	2	0
23	20	0	0	0	-2
24	16	0	0	0	2
25	22	0	0	0	0
26	6	0	0	0	0
27	10	0	0	0	0
28	15	0	0	0	0
29	4	0	0	0	0
30	21	0	0	0	0

Thirty experiments were conducted as per experimental plan. The order of experiment was randomized to avoid any bias in results. After the experimentation, each workpiece was taken out from precision lathe chuck. Cover from one side of workpiece was removed and SS pins were taken out. After that surface roughness of internal surface was measured with the help of roughness tester (Surftest SJ-301). A sampling length of 4 mm was selected for measurement of surface roughness (R_a). Surface hardness was measured with the help of micro hardness tester. Processed workpiece was measured at three different points to find out surface roughness as well as surface hardness. Average of three readings was considered as final value of surface roughness and surface hardness.

Table 4: Experimental Responses

Exp. No.	Order of Exp.	Independent Parameters (Coded)				Responses	
		A	B	C	D	PISF	PISH
1	12	-1	-1	-1	-1	27	31
2	17	1	-1	-1	-1	47	46
3	26	-1	1	-1	-1	21	26
4	23	1	1	-1	-1	37	43
5	2	-1	-1	1	-1	32	40
6	27	1	-1	1	-1	53	63
7	11	-1	1	1	-1	26	33
8	30	1	1	1	-1	42	52
9	18	-1	-1	-1	1	22	25
10	28	1	-1	-1	1	38	39
11	19	-1	1	-1	1	17	22
12	7	1	1	-1	1	28	35
13	25	-1	-1	1	1	26	32
14	29	1	-1	1	1	44	51
15	13	-1	1	1	1	21	25
16	1	1	1	1	1	35	42
17	5	-2	0	0	0	9	18
18	14	2	0	0	0	46	66
19	8	0	-2	0	0	49	51
20	9	0	2	0	0	27	42
21	3	0	0	-2	0	41	36
22	24	0	0	2	0	51	41
23	20	0	0	0	-2	49	53
24	16	0	0	0	2	34	35
25	22	0	0	0	0	36	41
26	6	0	0	0	0	32	45
27	10	0	0	0	0	30	42
28	15	0	0	0	0	35	44
29	4	0	0	0	0	35	45
30	21	0	0	0	0	36	39

A - Processing Time (Mins) B - Pole-Work Gap (mm)

C - Vibrating Frequency (Hz) D - Surface Rotational speed (RPM)

After measuring surface roughness and surface hardness, percentage improvement in surface finish (PISF) and percentage improvement in surface hardness (PISH) were calculated by comparing the average initial values of surface finish and surface hardness with average of three measured values of surface finish and surface hardness. The initial surface roughness values varies from 0.62 – 0.98µm and final surface roughness varies from 0.29-0.79 µm. The initial hardness was in the range of 93-104 Hv and the final hardness was measured in the range of 117-165 Hv. All the values of percentage improvement in surface finish (PISF) and percentage improvement in surface hardness (PISH) for all thirty experiments have been tabulated in Table 4.

4 Results and Discussions

After final experimentation on 30 workpieces, each and every workpiece was tested for improvement in surface finish and surface hardness on surface roughness tester and micro hardness tester respectively. Total percentage improvement in surface finish and surface hardness was measured and then processed using design expert software.

4.1 Parametric Effect on Percentage Improvement in Surface Finish

The variation of percentage improvement in surface finish with combined effect of various process parameters has been explained below.

4.1.1 Effect of Processing Time and Pole-Work Gap

The effect of simultaneous variation of processing time and pole-work gap on percentage improvement in surface finish (PISF) is shown in Figure 3. PISF is maximum at highest processing time (150 mins) and lowest pole-work gap (1 mm). PISF is minimum at lowest processing time and highest pole-work gap. At minimum processing time (30 mins), percentage improvement in surface finish is very less but it keeps on improving with the increase in processing time. After 150 mins of processing time, percentage improvement in surface finish is more than 100 % as compared to minimum processing time. Figure 3 further indicates that the effect of processing time on PISF at higher values of pole-work gap is less as compared to lower values of pole-work gap.

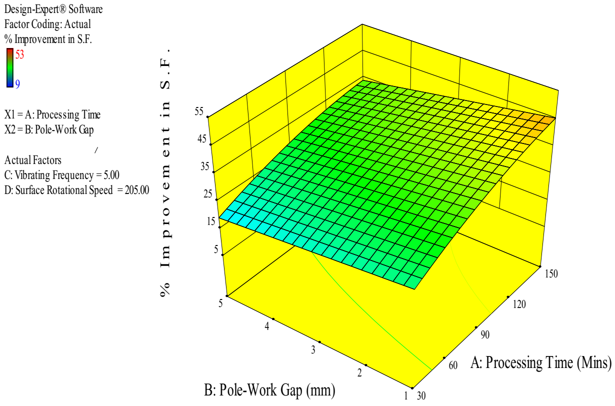


Figure 3: Effect of Simultaneous Variation of Processing Time and Pole-Work Gap on PISF

It is expected that magnetic flux density controls the striking force with which the pins strike on the surface. It is understandable that as the magnetic flux density reduces (due to higher pole-work gap), the striking force of the pins also decreases and hence PISF deteriorates.

4.1.2 Effect of Processing Time and Vibrating Frequency

The effect of simultaneous variation of processing time and vibrating frequency on percentage improvement in surface finish is visible in Figure 4. PISF is minimum at lowest vibrating frequency and lowest processing time.

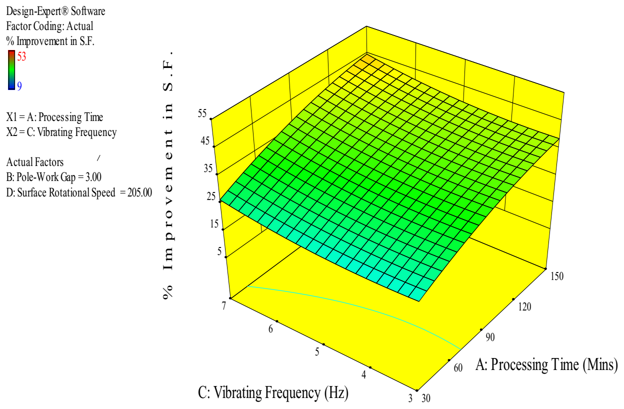


Figure 4: Effect of Simultaneous Variation of Processing Time and Vibrating Frequency on PISF

PISF keeps on increasing with increase in processing time and vibrating frequency of magnetic tool (magnetic pins). It is maximum at highest values of processing time (i.e. 150 mins) and vibrating frequency (i.e. 7 Hz). The effect of increase in vibrating frequency on PISF is less as compared to the effect of increase in processing time on PISF. It is due to the fact that with higher processing time and higher vibrating frequencies, total number of impacts produced by SS pins are increased hence reducing the surface irregularities. This is supported by the residual stresses data (Kumar, et al., 2012).

4.1.3 Effect of Processing Time and Surface Rotational Speed

It can be observed from Figure 5 that PISF is minimum at highest surface rotational speed and minimum processing time. It is due to the fact that at higher surface rotational speeds, magnetic tool does not get enough time within which it can strike on work piece surface with full magneto force (Kumar, et al., 2012). As the surface rotational speed is reduced, PISF is increased with respect to increase in processing time. PISF is maximum at lowest surface rotational speed and maximum processing time.

It is also visible from Figure 5 that as compared to surface rotational speed, effect of processing time is more. As compared to processing time of 30 minutes, PISF is nearly more than double after 150 minutes. Whereas change in PISF with respect to change in surface rotational speed is not as high as in the case of processing time. It shows that processing time is a major process parameter that influences the PISF on work surface.

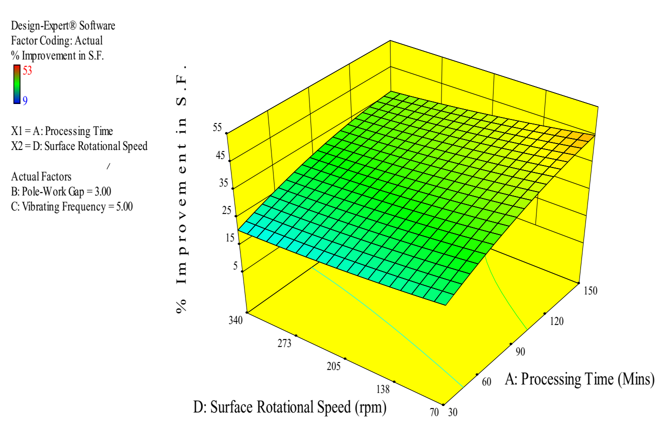


Figure 5: Effect of Simultaneous Variation of Processing Time and Surface Rotational Speed on PISF

4.1.4 Effect of Pole-work Gap and Surface Rotational Speed

Figure 6 indicates that PISF is maximum at minimum pole-work gap and lowest surface rotational speed. It keeps on decreasing with the increase in both pole-work gap and surface rotational speed. PISF becomes minimum at highest values of pole-work gap and surface rotational speed. This decremental trend in PISF is again due to the fact that at lower pole-work gap, magnetic field induced is stronger as compared to higher pole-work gap. At the same time, at lower surface rotational speed, magnetic tool have enough time within which it can strike on the work surface with full magneto force. Figure 6 also indicates that both the process parameters (pole-work gap and surface rotational speed) have approximately same influence on PISF.

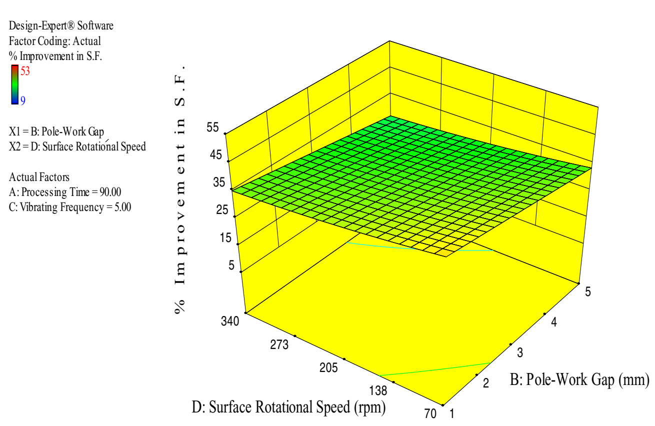


Figure 6: Effect of Simultaneous Variation of Pole-Work Gap and Surface Rotational Speed on PISF

4.2 Parametric effect on Percentage Improvement in Surface Hardness

The variation of percentage improvement in surface hardness with various process parameters has been explained in the following paragraphs.

4.2.1 Effect of Processing Time and Pole-work Gap

Figure 7 shows combined effect of processing time and pole-work gap on percentage improvement in surface hardness (PISH). It is evident from Figure 7 that PISH is maximum at maximum processing time and minimum pole-work gap. With the decrease in processing time and increase in pole-work gap, PISH keeps on decreasing.

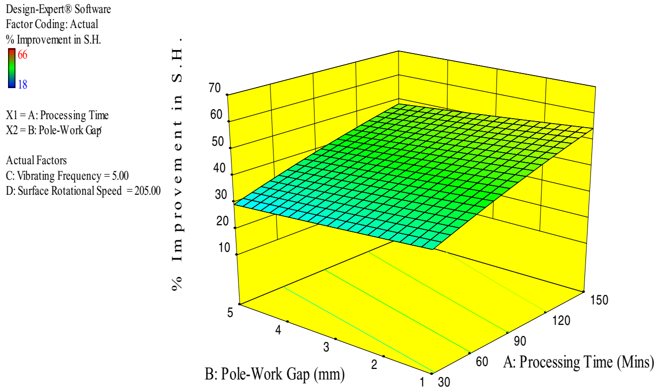


Figure 7: Effect of Simultaneous Variation of Processing Time and Pole-Work Gap on PISH

It is considered that with the increase in processing time, magnetic tool (pins) keep on striking the work surface for larger duration thus causing heavy peening effect on surface as evidenced from the residual stress plots (Kumar, et al., 2012). At the same time, with smaller pole-work gap, strength of magnetic field induced is high, which helps the magnetic tool to move and strike the surface with larger magneto force. As the processing time increases from 30 mins to 150 mins, there is large increase in PISH. But the effect of change of pole-work gap (from 1mm to 5mm) on PISH, is not as much higher as compared to processing time.

4.2.2 Effect of Processing Time and Vibrating Frequency

Figure 8 shows the effect of simultaneous variation of processing time and vibrating frequency on percentage improvement in surface hardness. Here, it is clear that PISH is maximum at highest vibrating frequency (7 Hz) of magnetic tool and maximum processing time (150 mins). PISH keeps on decreasing with decrease in vibrating frequency and processing time.

The reason behind good PISH at higher vibrating frequency may be due to the fact that at higher vibrating frequency, the number of impacts per unit time is more. So the net work done by magnetic tool on the surface seems to be enhanced. Thus PISH is increased by reducing surface irregularities. It is also clear from the Figure 8 that the effect of higher vibrating frequency on PISH is higher as compared to lower vibrating frequencies for the same processing time range.

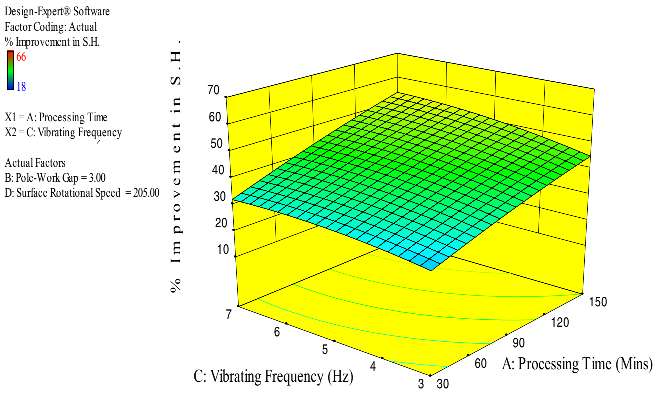


Figure 8: Effect of Simultaneous Variation of Processing Time and Vibrating Frequency on PISH

4.2.3 Effect of Processing Time and Surface Rotational Speed

Figure 9 shows the effect of simultaneous variation of processing time and surface rotational speed on percentage improvement in surface hardness (PISH). It is clear from Figure 9 that PISH is maximum at highest processing time (150 mins) and lowest surface rotational speed. As processing time is decreased and surface rotational speed is increased, PISH is decreased.

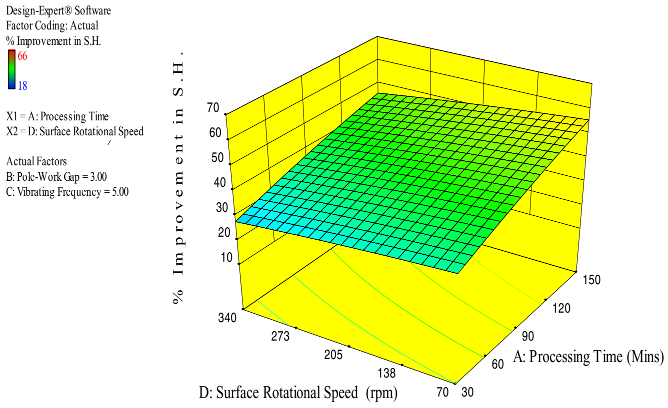


Figure 9: Effect of Simultaneous Variation of Processing Time and Surface Rotational Speed on PISH

It is also observed from Figure 9 that the effect of processing time on PISH is higher as compared to surface rotational speed. Increase in PISH from lowest processing time (30 mins) to highest processing time (150 mins) at lowest surface rotational speed (70 rpm) is higher than the increase in PISH within same time limits at higher surface rotational speed (340 rpm).

4.2.4 Effect of Pole-Work Gap and Vibrating Frequency

Figure 10 demonstrates the effect of simultaneous variation of pole-work gap and vibrating frequency on percentage improvement in surface hardness (PISH). It is clear from Figure 10 that the value of PISH is maximum at highest vibrating frequency (7 Hz) and lowest pole-work gap (1mm). The reason is, at highest vibrating frequency, number of impacts made by the magnetic tool is more (Kumar, et al., 2012).

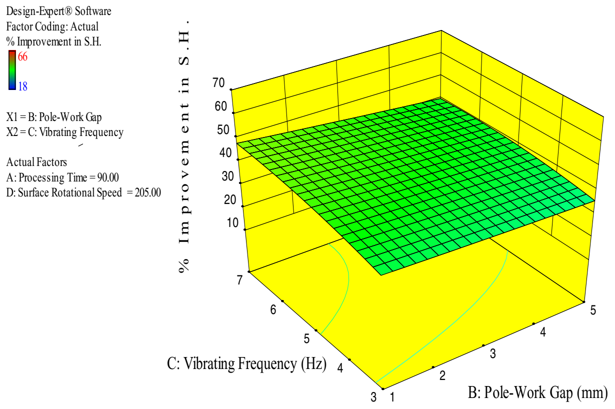


Figure 10: Effect of Simultaneous Variation of Pole-Work Gap and Vibrating Frequency on PISH

At the same time, at minimum pole-work gap, strength of induced alternating magnetic field is higher. So the force with which magnetic tool strikes the work surface and number of impacts is increased. Thus, PISH is increased by magnetic movement of tool on surface. As vibrating frequency is reduced and pole-work gap is increased, there is corresponding decrease in PISH. The value of PISH is minimum at maximum pole-work gap (5 mm) and minimum vibrating frequency (3 Hz).

4.2.5 Effect of Pole-Work Gap and Surface Rotational speed

Figure 11 shows the effect of simultaneous variation of pole-work gap and surface rotational speed on percentage improvement in surface hardness (PISH). It is clear from Figure 11 that PISH is maximum at lowest surface rotational speed (70 rpm) and minimum pole-work gap (1mm). It is due to the fact that at lower surface rotational speeds, magnetic tool has enough time within which it can strike on specific surface with greater impact before the surface moves.

Again at the same time, minimum pole-work gap (1mm) induces comparatively stronger magnetic field which in turn improve the strength of magnetic tool. As both the surface rotational speed and pole-work gap is increased, PISH decreased and become minimum at highest surface rotational speed (340 rpm) and maximum pole-work gap (5 mm).

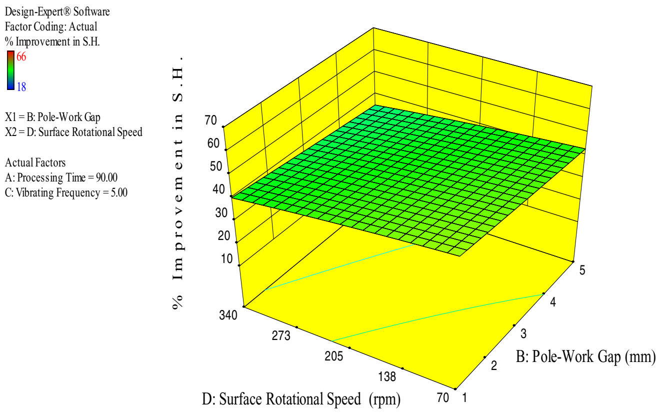


Figure 11: Effect of Simultaneous Variation of Pole-Work Gap and Surface Rotational Speed on PISH

4.2.6 Effect of Vibrating Frequency and Surface Rotational speed

Figure 12 shows the effect of simultaneous variation of vibrating frequency and surface rotational speed on percentage improvement in surface hardness (PISH).

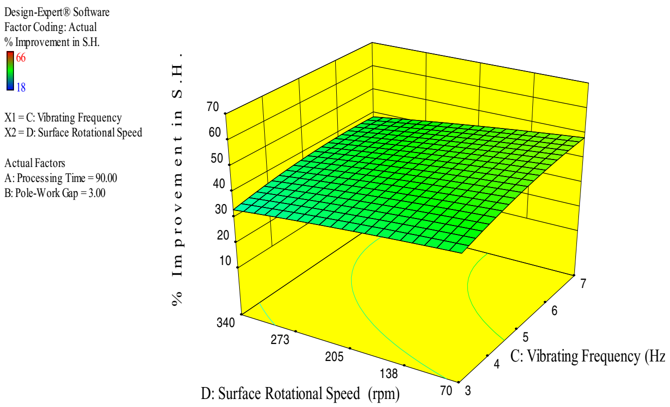


Figure 12: Effect of Simultaneous Variation of Vibrating Frequency and Surface Rotational Speed on PISH

It is clear from the Figure 12 that vibrating frequency of magnetic tool and surface rotational speed has great impact on PISH. Percentage improvement in surface hardness (PISH) is maximum at highest value of vibrating frequency (7 Hz) and minimum value of surface rotational speed (70 rpm). With the increase in surface rotational speed and decrease in vibrating frequency of magnetic tool, the value of PISH keeps on decreasing. It is due to the fact that at higher vibrating frequencies and lower surface rotational speed, net peening effect is improved (Kumar, et al., 2012). Thus net percentage improvement in surface hardness is also improved.

5 Conclusions

On the basis of experimental work related to surface modification of internal surface of brass tube with alternative magnetic field assisted stainless steel pins, following conclusions have been drawn:

(1) Internal surface of brass tubes can be modified by using SUS304 stainless steel pins in the presence of alternating magnetic field.

(2) The process parameters like processing time, pole-work gap, surface rotational speed and vibrating frequency of magnetic tool (magnetic pins) significantly influence surface finish and surface hardness of the processed surface.

(3) Processing time is the major parameter which affects both surface finish as well as surface hardness. After 150 minutes of processing time, percentage improvement in surface finish (PISF) and surface hardness (PISH) has been observed as more than double of that initial bored surface.

(4) Minimum pole-work gap gives stronger magnetic field which enhances the magnetic strength of magnetic tool. Considerable effect of minimum pole-work gap (1mm) on percentage improvement surface finish and surface hardness has been observed.

(5) The vibrating frequency of around 7 Hz resulted in better percentage improvement in surface finish as well as surface hardness.

(6) At lower surface rotational speed (70 rpm), considerable improvement in both surface finish as well as surface hardness has been observed.

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