Effects of Abrasive Media on Surface Roughness in Barrel Finishing Process

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Abstract: Barrel finishing is a common technique for surface finishing of industrial parts. Many factors such as working time, abrasive media, initial roughness and machining parameters of rotary barrel affect the final surface roughness of workpieces. Analysing these input parameters in order to obtain the least surface roughness as well as the least working time for barrel finishing of the specific samples, is not possible except by applying Design of Experiments method. Thus, the aim of the present paper is to improve the surface quality of the steel alloy CK45 samples in barrel finishing process, by investigating different combination of three abrasive particles including ceramics, steel balls and aluminium oxide as the abrasive media through design of experiments method. Initial roughness, working time and the combination of abrasive media are the input factors in the designed experiments, while the surface roughness is the output factor. Results show that the best surface roughness and working time have been achieved with the specific combination of steel balls and aluminium oxide particles as the abrasive media.

Keywords: Abrasive Media, Barrel Finishing, Design of Experiments, Mass Finishing, Surface Roughness

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1 INTRODUCTION

In order to precisely assemble industrial parts, they should have high surface quality. Since the surface of parts which are produced via most manufacturing processes is not smooth enough, therefore, a finishing process is applied to increase the surface quality. Although in a few manufacturing processes, such as electrical discharge machining, an acceptable surface quality can be achieved [1-6], the proper finishing processes such as grinding, polishing, burnishing and mass finishing are required to have a desired surface finishing [7-9]. By means of mass finishing techniques, many part can be coincidently polished and brightened. Barrel finishing process is a widely used technique of mass finishing, in which workpieces and abrasive media are loaded in a rotary horizontal barrel. Then, by rotating the barrel abrasive media rub all the external surfaces of the workpieces, resulting polished surfaces of parts[10-11].

Various advantages, such as low processing cost, low labor skill, no need to fixture and clamp, no limitation for shape, dimension and material of the workpieces [12], make this process proper for polishing and finishing of the wide range of parts including crank shaft, gears, chains, jewels and non-metallic parts [13-17]. There are many process factors which effect the final surface quality of the workpiece, including barrel setup parameters (rotational speed, dimension, geometry and etc.), characteristics of the abrasive media particles (shape, size and hardness) and physical and mechanical properties of the workpiece [18-19]. Because of wide range of input parameters, adjusting them to achieve the least surface roughness during the minimum working time is very difficult and for each special sample with individual geometry and material, many experiments must be performed to optimize input factors.

According to Boschetto and other studies, to investigate the effects of these parameters, the statically methods are conventionally used through experiments [12], [20]. Although many studies have been done to develop the mathematical model for movement of the abrasive particles and samples in the barrel finishing process (for example Mellmann's survey), the final calculated surface roughness was imperfect [21-24]. A number of researchers such as Parker, Bbosa, Puyvelde, Nakagawa have tracked the particles and analyzed the particle trajectory. They have observed the particles movement by common techniques such as positron emission method, magnetic resonance imaging and imaging processing techniques [25-28].

By these techniques, they could approximately calculate the working time, the surface roughness and the strain stress; however, these calculations were not precise [29]. Nityanand and other researcher said that the working time in barrel finishing process depends on the hardness of the workpieces, abrasive capability of the abrasive media and machining parameters, such as rotational speed [18-19], [30]. To decrease the working time Ding increased the rotational; however, the high rotational speed may damage the surface of specimens. Besides, the optimum finishing process is attained when the barrel is rotated at a speed just below the cascade point [31-33]. Another solution for reducing the working time is to increase the capability of the abrasive media which has been performed in this study. According to Chiancola survey, Shape, dimensions and hardness of the abrasive particles are the significant parameters to determine the capability of abrasive media [34].

According to above mentioned literature, to perfectly barrel finish each specific part with an individual shape and material, the input parameters must be set by means of design of experiments method. In addition, one of the major parameters in the barrel finishing process is the abrasive media's characteristics. Therefore, the purpose of this study is adjusting the input parameters for barrel finishing of the CK45 samples with the specific geometry by design of experiments method.

As mentioned, the main input parameter is the abrasive media in which different combinations of three types of abrasive media including steel balls, aluminium oxide and ceramics are selected and carefully applied. Moreover, the other input variables are the initial roughness of the samples and the working time of the process. Finally, the effects of these factors on the surface roughness of the samples are analyzed and investigated and the functional combination of abrasive media to obtain the least surface roughness and working time is introduced.

2 EXPERIMENTAL PROCEDURES

Samples were made of CK45 steel alloy, with the chemical composition presented in “Table 1”. The samples are cylindrical and produced by a Tabariz TN50 turning machine in 10mm diameter and 30mm height. Figure 1 shows a typical sample which is used in this study. To achieve different initial surface roughness, the samples are machined with three different feed rates: 0.08, 0.16 and 0.24 mm/rev which respectively leads to three initial roughness: 6.14, 8.96 and 11.90µm.

Table 1 Chemical com positions of CK45 steel

C (%)	Si (%)	Mn (%)	P (%)	S (%)
0.42-0.50	0.15-0.35	0.50-0.80	0.035	0.35

A horizontal barrel finishing machine was manufactured and used in this study. The barrel is hexagonal and was made of PVC sheets. The diameter and the length of the barrel are 230mm, which results in 9 litter capacity. The rotational speed of barrel was 54 rev/min. Figure 2 shows the schematic drawing and the applied barrel finishing machine.

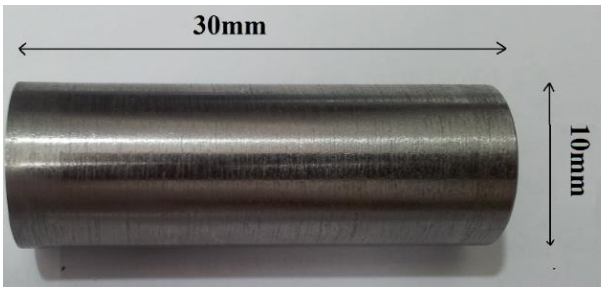

Fig. 1 A sample before barrel finishing process.

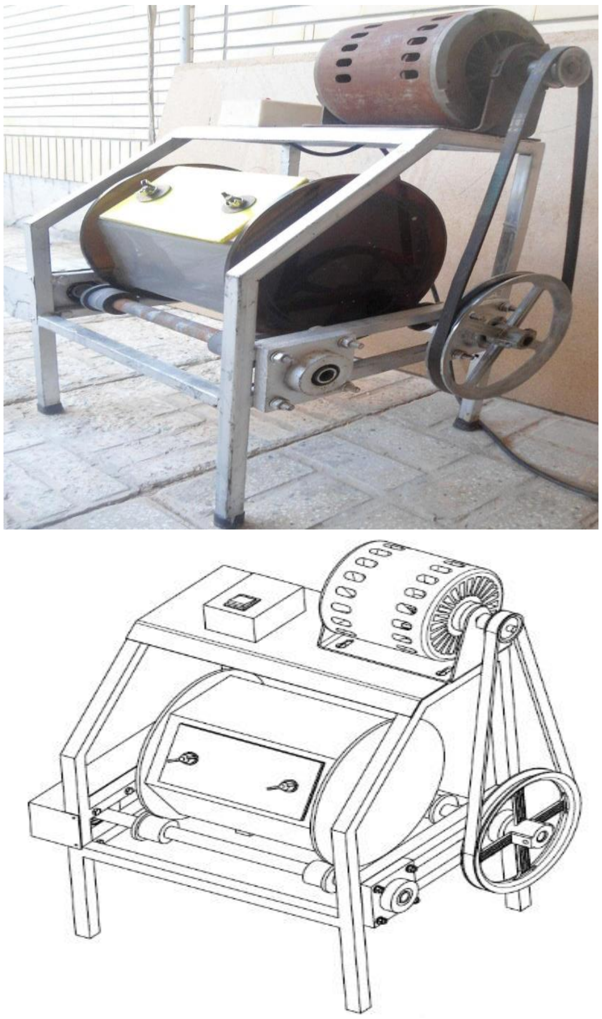

Fig. 2 Applied barrel finishing machine.

Steel balls, aluminum oxide and ceramics particles are the three types of abrasive media which are used in the experiments. Steel balls are in 3mm diameter and with 7.8 g/cm3 density. The ceramics particles were in cylindrical shape (Φ=5mm, length=10mm) and 2.9 g/cm3 density. The mesh of aluminum oxide (Al_2O_3) grit is 80 and the density is 1.8 g/cm3. Figure 3 shows the three used abrasive media. It should be noted that, after each experiment, the abrasive media was cleaned and washed with water and nitric acid. The surface roughness of the samples was measured by a portable roughness tester of Mahr Company.

Fig. 3 Three types of used abrasive particles.

3 DESIGN OF EXPERIMENTS

The three input factors in the experiments are: working time, initial roughness and type of abrasive media. The experiments were performed in 4 levels for working time as 1 hour, 2 hours, 3 hours and 4 hours. The initial roughness of the specimens was in 3 levels as 6.14µm, 8.96µm and 11.90µm. For the different combinations of the abrasive media out of three abrasive particles including, steel balls, aluminum oxide and ceramic particles, nine levels were assumed. The total weight of the abrasive media, loaded in each experiment in the barrel was 5kg. The combination was set as percentage of total weight. The three input factors and their levels are shown in “Table 2”.

The experiments were performed in the full factorial method and the effects of all factors was investigated on the surface roughness of specimens. As shown in “Fig. 4”, the surface quality was remarkably improved after the barrel finishing process. In “Table 3 and 4”, the measured roughness and the reduction of roughness of the samples in each experiment is presented respectively. For each experiments, five samples were selected and their surface roughness were measured and averaged. Totally 84 experiments were performed in this study.

Table 2 The input factors and their levels

Input Factors		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
Working time (hrs)		1	2	3	4	-	-	-	-	-
Initial roughness (μm)		6.14	8.96	11.90	-	-	-	-	-	-
Abrasive media (%wt of total weight)	Al_2O_3	-	100 %	-	50%	-	75%	50%	25%	33%
	Steel balls	100 %	-	-	-	50%	25%	50%	75%	33%
	Ceramics	-	-	100 %	50%	50%	-	-	-	33%

Fig. 4 Samples before and after barrel finishing. (Working time= 2 hrs., initial roughness= 8.96µm, abrasive media: 75% steel balls and 25% aluminum oxide, final surface roughness= 3.75µm).

Table 3 The measured surface roughness of the samples in the experiments

Working time (level)	Initial Roughness (level)	Abrasive media								
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
		Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)	Ra (µm)
1	1	-	-	-	-	-	5.46	4.82	3.53	-
2		-	-	-	-	-	5.01	4.09	2.53	-
3		-	-	-	-	-	4.58	3.69	1.91	-
4		-	-	-	-	-	4.23	3.21	1.44	-
1	2	8.15	4.82	6.87	7.11	6.7	7.9	7.1	4.62	6.9
2		7.64	3.9	5.828	6.718	5.69	7.63	6.28	3.75	6.18
3		7.32	3.42	5.201	6.325	5.08	7.09	5.81	3.08	5.77
4		6.974	3.05	4.705	5.83	4.53	6.61	5.11	2.38	5.13
1	3	10.805	7.96	9.9	10.1	9.02	10.80	8.91	6.57	9.19
2		10.485	6.13	8.869	9.45	8.25	10.43	8.51	5.38	8.64
3		10.078	5.16	8.015	8.831	7.41	9.9	7.62	4.21	8.13
4		9.769	4.661	6.38	7.95	6.25	9.21	6.98	3.56	7.34

Table 4 The reduction of surface roughness in the experiments

Working time (level)	Initial Roughness (level)	Abrasive media								
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
		% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction	% Ra reduction
1	1	-	-	-	-	-	11.07	21.49	42.50	-
2		-	-	-	-	-	18.40	33.38	58.79	-
3		-	-	-	-	-	25.40	39.90	68.89	-
4		-	-	-	-	-	31.10	47.71	76.54	-
1	2	9.04	46.20	23.32	20.64	25.22	11.83	20.75	48.43	22.99
2		14.73	56.47	34.95	25.02	36.49	14.84	29.91	58.14	31.02
3		18.30	61.83	41.95	29.40	43.30	20.87	35.15	65.62	35.60
4		22.16	65.95	47.48	34.93	49.44	26.22	42.96	73.43	42.74
1	3	9.20	33.10	16.80	15.12	24.20	9.24	25.12	44.78	22.77
2		11.89	48.48	25.47	20.58	30.67	12.35	28.48	54.78	27.39
3		15.31	56.63	32.64	25.78	37.73	16.80	35.96	64.62	31.68
4		17.90	60.83	46.36	33.19	47.47	22.60	41.34	70.08	38.31

4 RESULTS AND DISCUSSION

In the following, the effect of each factor is individually discussed on the surface roughness of the specimens.

4.1. The Effect of Working Time on the Surface Roughness

Obviously, by increasing the working time, the surface roughness is decreased and it is independent of the other factors. In fact, one solution to higher surface quality, is to increase the working time. In the "Fig. 5", the surface roughness is plotted against the working time for four different conditions.

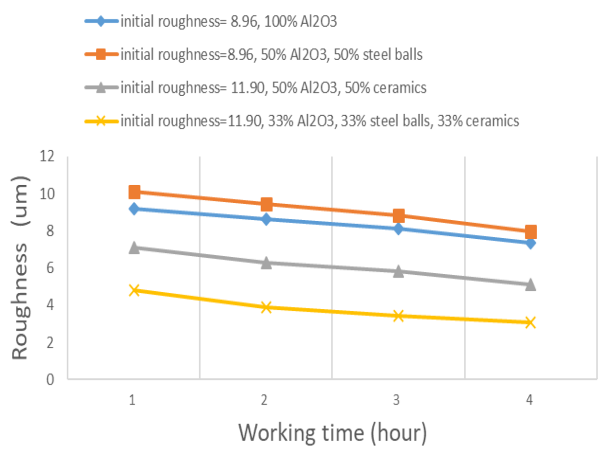

Fig. 5 Surface roughness of the samples in four conditions.

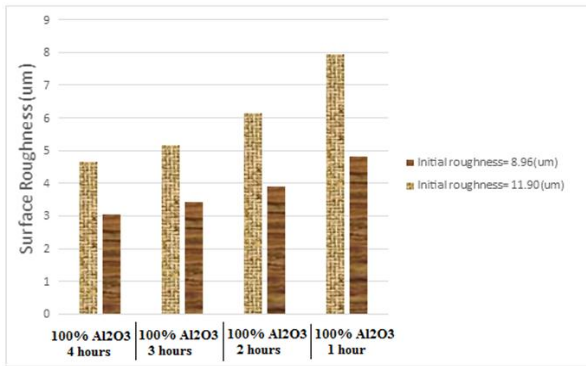

Fig. 6 Effect of initial surface roughness on the final surface roughness in four conditions.

4.2. The Effect of Initial Roughness on the Surface Roughness

The initial surface roughness plays a significant role on the final surface roughness of the samples in the barrel machining process. A sample with the higher initial surface roughness resulted in a rougher surface, comparing to the sample with lower surface roughness, in the identical machining conditions. It means that the reduction of surface roughness is more for a sample with the less initial surface roughness. Figure 6 shows the effect of initial surface roughness on the finial surface roughness for four different conditions and "Fig. 7" shows the effect of initial surface roughness on the amount of reduction of surface roughness for the same conditions.

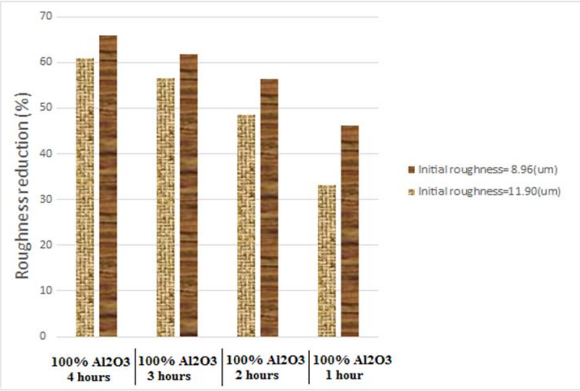

Fig. 7 Reduction of surface roughness in four conditions

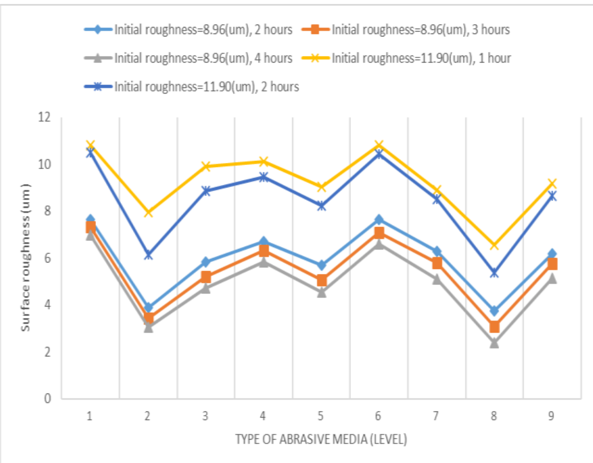

Fig. 8 Surface roughness for the nine levels of abrasive media in five conditions.

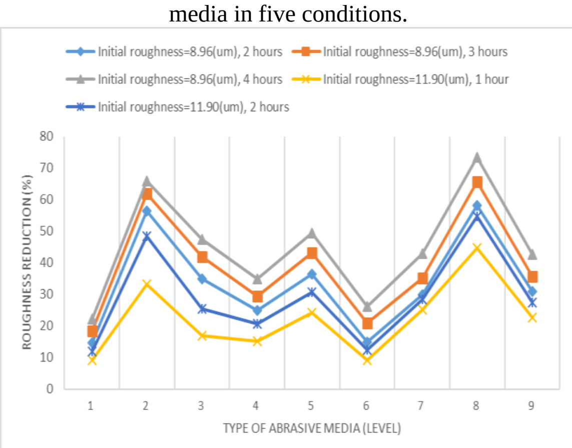

Fig. 9 Reduction of surface roughness for the nine levels of abrasive media in five conditions.

4.3. The Effect of Abrasive Media Particles on Surface Roughness

The effect of abrasive media particles on the surface roughness is demonstrated for all the nine levels of abrasive media for five conditions in “Fig. 8”. Figure 9 shows the reductions of surface roughness for those conditions. According to the “Figs. 8 and 9”, the best surface quality has been obtained by using eight levels of particle combinations, which is 75% steel balls and 25% aluminum oxide, as the abrasive media. Also, by applying this combination of abrasive media, working time can be considerably reduced. For instance, the surface roughness which is achieved by using the combination of 75% steel balls and 25% aluminum oxide as the abrasive media during only one hour, is equivalent to the surface roughness of using 100% ceramics or 50% ceramics and 50% steel balls in four hours.

5 CONCLUSION

In the present paper, the effects of the three factors (working time, initial surface roughness and the type of abrasive media particles) have been investigated on the surface roughness of steel alloy samples. The results can be summarized as the following:

- Generally, by increasing the working time, the surface quality is improved and this result is independent of the effect of other factors.
- A sample with lower initial roughness leads to smoother finished surface. In addition, by reducing the initial surface roughness, the reduction in surface roughness through barrel finishing process, is also raised.
- According to the results of the experiments, the combination of 75% steel balls and 25% aluminum oxide particles resulted in the best surface roughness. By using this combination as the abrasive media, the working time and also the processing cost can be reduced.

6 ACKNOWLEDGMENTS

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