Influence of Vibratory Finishing Process by Incorporating Abrasive Ceramics and Glassy Materials on Surface Roughness of CK45 Steel

P. Saraeian & M. Gholami
Department of Materials Engineering,
Islamic Azad University of Najafabad Branch, Isfahan, Iran
E-mail: p_saraeian@iaun.ac.ir, me.gholami2011@yahoo.com

A. M. Behagh & O. Behagh
Arshan Sanat Jam Co. ltd, Isfahan, Iran
E-mail: a.behaq@gmail.com, behagh.omid@gmail.com

H. R. Javadinejad
Department of Materials Engineering,
Isfahan University of Technology, Isfahan, Iran
E-mail: hr.javadi@pa.iut.ac.ir

M. S. Mahdieh*
School of Mechanical Engineering, College of Engineering,
University of Tehran, Tehran, Iran
E-mail: s_mahdieh@ut.ac.ir
*Corresponding author

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Abstract: The vibratory finishing is one of the important mass finishing processes. This can be applied for finishing many metallic and non- metallic components using abrasive materials such as steel, ceramic, natural materials and etc. The vibratory finishing process is used for some purposes such as surfaces polishing, deburring, oxide layer removing and rounding the edges. Evaluation of surface roughness changes with time that is one of the important parameters during the vibratory finishing process. In this study, the effects of the working time and abrasive materials are investigated on the surface roughness changes of CK45 steel samples. The ceramic, glass and mixed abrasive particles are used as the abrasive media. The experiments are performed at different time from 10 to 120 minutes in the dry environment. Finally, the surface roughness values of samples were measured and then fitted by a regression equation for description of the surface roughness changes with time. According to the results, the maximum surface finish was obtained after 120 minutes by using mixed abrasive materials. The surface roughness improved approximately 60%.

Keywords: Abrasive particles, Mass finishing, Surface roughness, Vibratory finishing

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Biographical notes: P. Saraeian received his PhD in Mechanical Engineering from University of Tarbiat Modares in 2012. **M. Gholami** received his MSc in Mechanical Engineering from Islamic Azad University of Najafabad Branch, in 2015. **A. M. Behagh** received his MSc in Mechanical Engineering from Isfahan University of technology in 2012. **O. Behagh** received his BSc in Mechanical Engineering from Islamic Azad University of Najafabad Branch, in 2010. **H. R. Javadinejad** is PhD candidate in Materials Engineering from Isfahan university of technology. **M. S. Mahdieh** received his PhD in Mechanical Engineering from University of Tehran in 2016.

1 INTRODUCTION

The finishing refers to a wide variety of processes that are used to produce surfaces with specific characteristics such as dimensional accuracy, tolerances, geometry, and good surface properties. The finishing processes are usually the last step of the industrial processes in manufacturing the components [1]. Although some modern machining processes such as electrical discharge machining produce an acceptable surface quality [2-4], applying finishing processes including grinding, polishing and burnishing are necessary to achieve smooth and well-polished surfaces [5]. Since 1950, the vibratory finishing process is widely used to improve the appearance, surface hardness and abrasion resistance of metallic, ceramics and plastics components using different types of abrasives materials such as steel balls, ceramic and natural materials [6].

The finishing environment can be dry or wet. Other parameters affecting the process are the frequency and amplitude of vibration, size, shape and properties of the finishing tools. Appropriate operation system is designated through operator experience or trial and error. The vibratory finishing process time is significantly longer than the other finishing methods. Therefore, reducing the time and improving the efficiency of process are the important overall objectives of researchers [7]. Wang et al., [9] measured the distribution of normal contact forces in a bowl-type vibratory finisher and also compared the roughness and hardness changes over aluminium AA1100-O and AA6060-T6. The principal variables include media particle size, degree of lubrication and the duration time of the vibratory finishing.

They proposed that because of interaction between the media and the workpiece and subsequent plastic deformation, these parameters will have a key role to play in hardness and roughness changes. Uhlmann et al., [10] considered the transient period of vibratory finishing and presented a new model to protect the surface roughness change after a given process time. Despite past approaches concentrating on mass or diameter loss of the workpiece, the model is based on geometric changes of the roughness-profile during the transient period of mass finishing. It can be used to estimate process times required to attain a favourable roughness of a workpiece.

Arne et al., [11] investigated vibratory finishing and proposed a process model merging both Discrete Element Method (DEM) and experimental results. They also discussed the relevant process parameters of surface topography formation over steel rods with different topographies. Based on the data presented, there is a good consistent between material removal model and experiments. Song et al., [12] experimentally investigated the influence of chemical solutions and process parameters like media size and impact frequency on the metal removal and resultant surface roughness of vibratory finished workpiece. They also developed a method in order to study the effect of chemical solution and also to optimize processing time that leads to a desired surface roughness.

The low capital investment, ability to produce desirable finishes of multiple working surface and needs of less operator skill have made the vibratory finishing of interest but its processing time is relatively high as compared to other processes like grinding. So, lower process time and optimized productivity are the significant challenges must be taken to account to reduce costs. According to the pervious results, considerable researches have not been done on the effects of the abrasive material composition; its influence on the process time and changes of surface roughness. The main objective of the present study is to investigate the effect of process time and types of abrasive media on the surface roughness of CK45 castings.

2 EXPERIMENTAL

2.1. Drilling and cleaning

The specimens were cut and then drilled using TN50 Tabriz milling machine. The vital goal in this section is to achieve similar workpieces in view of the length and weight. All samples were completely cleaned from surface contaminations by using a solvent and then high pressure airing.

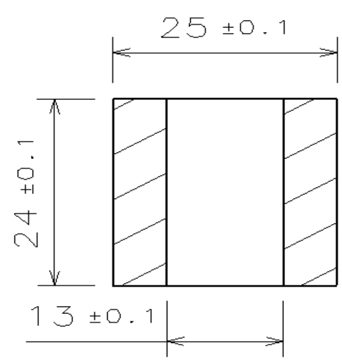

Fig. 1 The workpiece dimensions plane (cm)

2.2. Vibratory finisher and abrasive ceramic media

The experiments were considered as full factorial design and 10 to 120 minutes' period. The present measurements were conducted in the finisher, having a volume chamber of 12 litters and motor rotational speed of 3000 RPM (Fig. 2).

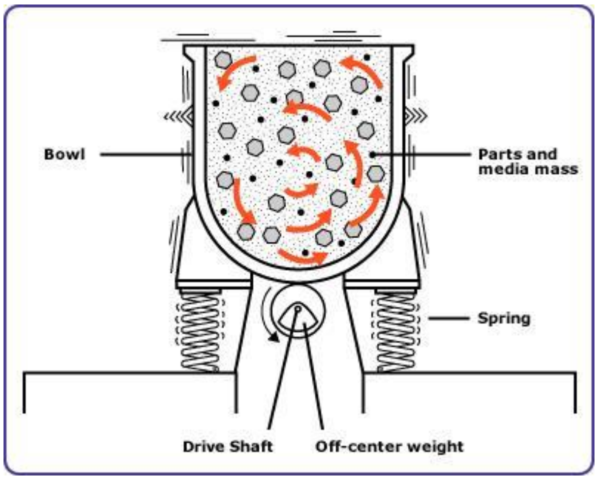

Fig. 2 The Schematics of the bowl-type vibratory finisher

All 12 prepared samples were vibratory finished for 120 minutes (Each sample was pulled out in 10 min.) in a media consisting of abrasive ceramic particles with disorder form and density of 1362-2002 kg/m3 (Fig. 3).

Fig. 3 The Abrasive ceramic particles.

After vibratory finishing process, all samples were numbered and the surface roughness was measured in four sections of surfaces. The average value for reference sample (Num0) was 1.849.

2.3. Vibratory finisher and abrasive glassy media

It was performed on 12 new specimens and similar to the former experiment, but the media consists of abrasive glassy particles. The particles were popularly globular with diameter from 850 to 1100 µm and made from siliceous compounds (Fig. 4). According to information from producer, the density and hardness of balls were 1.3 kg/cm3 and 5.5 Mohs, respectively.

Fig. 4 Abrasive glassy particles

2.4. Vibratory finisher and abrasive glassy-ceramic media

It was carried out as two former experiments, whereas the media compromised of both two ceramic and glassy grains in 2.1 ratios. Finally, the data was first supplied to the Excel and Minitab software and then the results were analyzed.

3 RESULTS AND DISCUSSIONS

The average values of surface roughness from surface roughness tester are reported in Table 1. According to the data presented in table 1, the changes of roughness are schematically shown in Fig. 5.

Table 1 The average values of surface roughness from surface roughness tester for different abrasive materials.

		Surface roughness values average(µm)		
Samples	Time(min)	Glassy	Ceramic	Glassy-ceramic
1	0	1.849	1.849	1.849
2	10	1.693	1.791	1.641
3	20	1.592	1.714	1.492
4	30	1.480	1.566	1.397
5	40	1.453	1.481	1.303
6	50	1.410	1.417	1.242
7	60	1.386	1.369	1.113
8	70	1.361	1.251	1.024
9	80	1.328	1.246	0.978
10	90	1.233	1.117	0.938
11	100	1.167	1.090	0.931
12	110	1.049	1.046	0.889
13	120	1.011	0.981	0.853

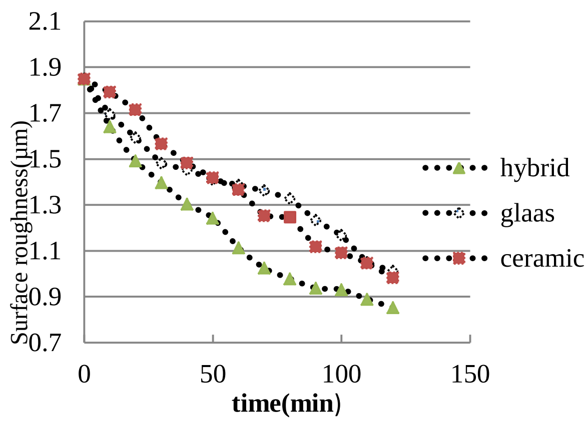

Fig. 5 The changes of surface roughness per time

According to Fig. 5, the greatest changes of surface roughness can be seen after 120 minutes using mixed abrasive materials. Generally, surface wear depends on the speed and pressure of the vibratory finishing process. In this study, the speed was constant but pressure changed because of different density of abrasive material. Therefore, the changes of surface roughness are directly a function of abrasive material type. The results showed that the changes of surface roughness using ceramics and glassy particles are approximately same. Ceramics particles are denser than glassy particles. On the other hand, glassy particles have higher hardness than ceramics particles. This different between density and hardness of ceramics and glassy particles balances their abrasive properties.
As a result, changes of surface roughness related to both abrasive materials were same. By mixing ceramics and glassy particles, the vibratory finishing process was performed better and changes of surface roughness were higher than two other conditions. This is because of simultaneous effects of higher hardness and density of glassy and ceramics particles respectively. Also, many cavities are on steel samples surfaces that ceramics particles do not able to penetrate into them. On the other hand, glassy particles require too time for removing these cavities due to their low density. Therefore, using mixed abrasive materials causes ceramics particles drive glassy particles to surface cavities and produce higher pressure due to their higher density. As a result, total time of the vibratory finishing process decreases and surface smoothness obtains sooner. These changes are clearly marked in Fig. 5 and the results are as follows:

- Surface roughness improved approximately 47% than the initial state in dry environments and at 120 minutes using the ceramic abrasive materials in the vibratory finishing process.
- Surface roughness improved approximately 40% than the initial state in dry environments and at 120 minutes using the glassy abrasive materials in the vibratory finishing process.
- Surface roughness improved approximately 54% than the initial state in dry environments and at 120 minutes using the ceramic and glassy abrasive materials in the vibratory finishing process.

According to these results, the vibratory finishing process on CK45 steel by using the combination of ceramic and glassy abrasive materials in dry environment for 120 minutes is an appropriate and fast method to produce a smooth surface. This leads to decreasing the process time as the biggest problem of the vibratory finishing.

3.1. Analysis of output variables

Independent experiment errors and constant variance value are the postulates for variance analysis. To prove that, the value of errors and processing data which are equal to surface roughness numbers, should be compared to each other (Fig. 6).

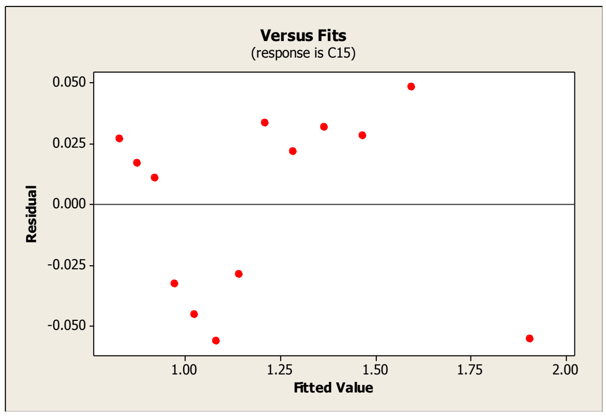

Fig. 6 Residual versus fitted values for output

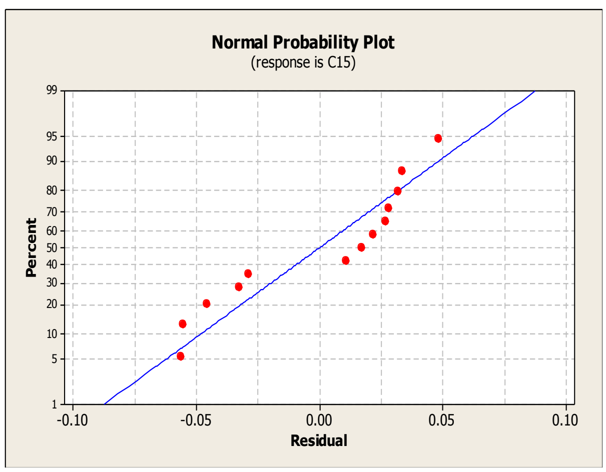

Fig. 7 The normal probability distribution diagram for regression

It is clear that the spots distribute randomly and do not obey any particular model. So, it confirms the independency of errors. The probability distribution diagram (Fig. 7) analyzes the normal distribution assumption of the tests errors. The analysis is the primary condition for variance analyzing. R^2 or R-Sq is one of the statistic features for regression analysis. As R-Sq value increase, the results would be more accurate and reliable. To prove the desirability of analysis, the R-Sq value should also be high well enough and close to the R-Sq. Table 2 presents the accuracy of regression model.

Table 2 The final model for data regression

Predictor	Coef	SE Coef	T	P
Constant	1.90401	0.0276	69	0
t	-0.00736	0.003563	-27.62	0
	R-Sq = 98.6 %		R-Sq(adj) = 98.4%	

Finally, for of vibratory finishing using both ceramic and glassy materials, the results in terms of the processing time could be summarized in equation (1) as follow:

$$Ra = 1.90 - 0.0984\, t^{1/2} \quad (1)$$

3.2. Model verification test

Initially, a specimen is placed in machine for 55 minutes and then the surface roughness is measured over four areas, as previously stated (Table 3).

Table 3 Final model for data regression

Time(min)	Surface roughness (µm)				Average(µm)
55	1.178	1.351	1.123	1.034	1.1715

On the other hand, by considering t= 55 min., theoretical value of Ra is 1.17024. The difference between theory and experimental number is about 0.00126 which leads to errors value of 0.1%.

4 CONCLUSION

Vibratory finishing is a multiple process for metallic and non-metallic materials. Reducing time and improvement of productivity are the major challenges to reduce the final costs. In this research, by combining ceramic and glassy abrasive materials, the initial surface roughness in dry-vibratory finisher for 120 minutes is reduced to half and regression model had a good conformity with experimental one. Following results are proposed on the basis of this research's team experience and observations:

- The initial surface roughness of sample which was finished vibratory using abrasive ceramic particles, in dry media and for 120 minutes reduced about 47%. The difference between regression and experimental model was favorable (0.007 µm).
- The initial surface roughness of CK45 workpiece which was finished vibratory using abrasive glassy particles, in dry media and for 120 minutes improved about 40%. The difference between regression and experimental model was 0.0012 µm
- By utilization both ceramic and glassy particles and for the same time and media as others, the surface roughness reduced about 54%. The difference between regression and experimental model was too negligible (0.00126 µm).

ACKNOWLEDGMENTS

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