An investigation into ball burnishing process of carbon steel on a lathe

A. A. Ibrahim
Mechanical Engineering Department, Shoubra faculty of Engineering, Benha University, Egypt
E. mail: akader60@hotmail.com

ABSTRACT

Burnishing is a chipless finishing method, which employs a rolling tool, pressed against the workpiece, in order to achieve plastic deformation of the surface layer.

A new burnishing tool was introduced in this investigation which enables both single and double ball burnishing process in site after turning without releasing the workpiece. Effect of burnishing parameters which are burnishing feed, burnishing speed, and burnishing force upon final surface texture (roughness and roundness) were demonstrated.

Burnishing results showed significant effectiveness of the burnishing tool in the process. The surface roughness and roundness error of the turned test specimens were improved by burnishing. For the treated material in this investigation, the best results of surface roughness and roundness error were obtained with both single and double ball burnishing with a burnishing force of 170N. The minimum surface roughness was obtained at a feed rate 0.11 mm/rev. and a speed of 60.3 m/min. The smaller roundness error also can be achieved by using burnishing speeds ranging between 60.3 to 85.7 m/min. with a burnishing feed of 0.11 mm/rev. The results of double ball burnishing were better than that of single ball burnishing.

KEYWORDS

Ball burnishing, Surface roughness, Roundness error

1.INTRODUCTION

The surface finish quality and roundness error of the machined components are an essential requirements due to its direct effects on the function of the components. Finishing processes such as hard cutting, grinding, polishing, and lapping are commonly used to improve the surface finish of the machined components. Some researches have been carried out recently to improve surface characteristics by using ball burnishing process. Ball burnishing process, as shown in fig. 1, is one of the surface finishing processes that results in a plastic deformation on the workpiece surface by using a ball or a roller [1,2]. Plastic flow of the original asperities occurs when the yield point of the workpiece's material is exceeded [3]; consequently the asperities will be flattened.

The improvement of the surface roughness through the burnishing process generally ranged between 40% and 90% [3, 4]. Compressive stresses are also induced in the surface layer, giving several improvements to mechanical properties. Burnishing can improve both the surface strength and roughness [5].

The effects of several parameters for ball burnishing process, having significant effects on surface roughness, were investigated using Taguchi's method to conduct the matrix experiment to determine the optimal ball burnishing process parameters. Parameters that have influence in the process are: the normal force, the burnishing feed, and speed. Original roughness is also expected to exert an important effect [5].

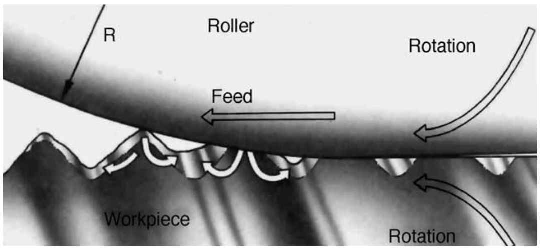


Fig. 1 Principle of burnishing process

The aim of this study was mainly to introduce a new burnishing tool which enables both single and double ball burnishing process in site after turning on a conventional lathe without releasing the workpiece. Effect of burnishing parameters which are burnishing feed, burnishing speed, and burnishing force upon final surface texture (roughness and roundness) were demonstrated.

2. EXPERIMENTAL INVESTIGATION

As mentioned, the main concern of this work is to examine the use of a new ball burnishing tool which will be used to improve surface characteristic such as surface roughness and roundness error as these factors playing an important role on the required tolerance and fit especially during assembly of parts. The effects of burnishing parameters; namely; burnishing speed, feed, and burnishing force on surface roughness and roundness error are comprehensively studied through this work.

2.1 Burnishing tool

The tool employed in the experiments was designed and constructed, as shown in (Fig. 2). It consists of a ball made out of Carbon chromium steel, with a diameter of 8 mm, and having 80 HRC and arithmetic mean average of surface roughness (Ra) 0.01. The ball is in solid contact only with the surface to be burnished, and is guided by 12 idler balls to be free to roll in any direction on the surface of the work piece. One tool was used for single ball burnishing, while two tools were employed for double ball burnishing as shown in fig. 3.

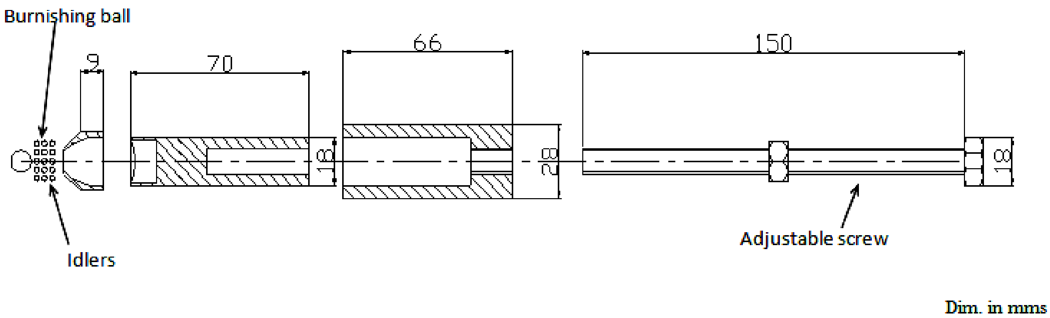


Fig. 2 Burnishng tool

The shank of one of the burnishing tools is designed in such a manner that it can be simply mounted or fixed onto the tool holder of the lathe machine, while the other tool is mounted o a special holder. This holder is fixed on the lathe saddle to move with it as one part. Then variable feed rates for burnishing were applied for the tolls by the lathe saddle. The tools were properly aligned and leveled using laser total station. As shown in the figs. 2, 3 each burnishing tool is ended with a hexagonal head adjustable screw which was tightened with a torque arm wrench to obtain the required burnishing forces.

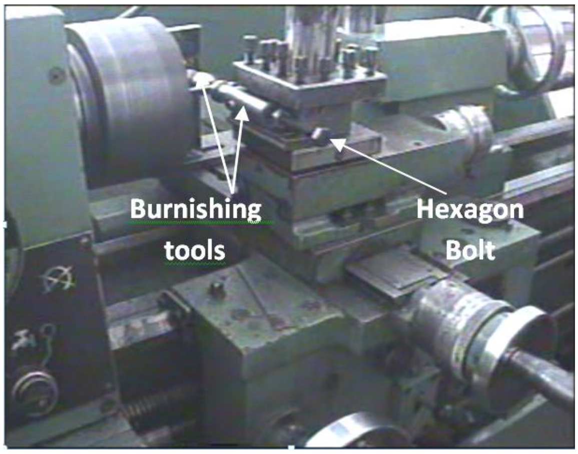


Fig. 3 Installation of burnishing tools on a lathe

This setup has the following advantages,

- The normal force is constant, controlled by torque arm wrench; the process is then consistent and easy to reproduce;
- The ball can rotate freely in any direction; this minimize the sliding contact with the workpiece;
- The tool can be installed on a regular or CNC lathe; burnishing can be thus carried out with the workpiece in the same clamped position as for a previous operation (usually turning);
- The tool has a long life and it is easy to maintain.

2.2. Material of the test specimens

The material used in this study was carbon steel of 0.18%C. This material was selected due to its importance in industry. The chemical composition is 0.18%C, 0.21%S, and 0.55%Mn, and mechanical properties are σ_u= 380 N/mm^2, and BHN= 121.

The specimen configuration is shown in fig. 4. Turning and burnishing processes were applied to the diameter 30mm.

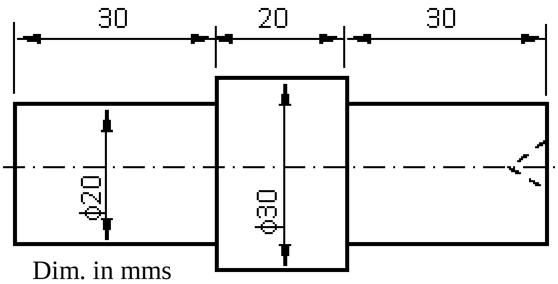


Fig. 4 Configuration of test specimen

2-3 Setup for the experiments

The workpiece to be burnished is clamped by the three-jaw chuck of the lathe and guided from other side by the lathe tailstock. The burnishing process was applied after turning without releasing the workpiece from the lathe chuck to keep the same turning alignment.

Initial dry turning conditions were unified for all workpieces as follows:

Cutting speed= 57 m/min., depth of cut =0.25 mm, feed rate= 0.32 mm/rev., and tool nose radius of 0.2 mm.

As the aim of this investigation was to study the effect of the new burnishing tool in both single and double ball burnishing process upon final surface texture (roughness and roundness), and to study the effect of burnishing parameters namely burnishing feed, burnishing speed, and burnishing force upon final surface texture (roughness and roundness). The applied Burnishing processes parameters and conditions are listed in table 1.

Table 1. Burnishing parameters and conditions

Burnishing feed(f) mm/rev.	0.03, 0.06, 0.11, 0.17, and 0.21
Burnishing speed m/min.	10.5, 29.6, 60.3, 85.7, and 116.5
Burnishing force (P)N	80, 170, and 250
Burnishing conditions	Lubricant

In this work, produced surface roughness, and roundness error were measured after burnishing process.

The surface finish of the burnished specimens was measured using Mirotoyo talysurf model 402 series 178. The measurements were carried out across the lay using diamond stylus of radius 2.5 microns and adjusted meter cut-off 0.8 mm. Five readings of surface roughness (measured by Ra) were taken for each specimen, and the average values are calculated.

Roundness error was measured using Mitotoyo ROUNDTEST RA-112-122. For better results the arithmetic average of three readings was calculated.

The pre-burnished surface of the test specimens were monitored by measuring of surface roughness and roundness values for four specimens which were turned under the same turning conditions as mentioned before.

3. Results and discussion

To study the effectiveness of the new burnishing tool, and effect of burnishing parameters on the burnished surface roughness and roundness the experimental results are plotted as shown in figs. 5, and 7-11. The relations are drawn for single ball and double ball burnishing to study which one has more appreciable effect.

The results of turned specimens were as follows: The average of Surface roughness (Ra) and roundness error (O) for four specimens is 2.5μm, and 7.3 μm respectively.

The results of burnishing tests and discussion are as follows:

3.1 Effect of burnishing parameters on surface roughness

3.1.1 Effect of feed rate

As mentioned before five burnishing feeds were selected for this test. The effect of feed rate (f) was studied with constant burnishing speed of 60.3 m/min. and at different values of burnishing force (P) to study the interaction between the two parameters (f, P).

The relations are plotted as shown in fig. 5. The results of using single ball burnishing are shown in fig. 5a, while fig. 5b shows the results of double ball burnishing.

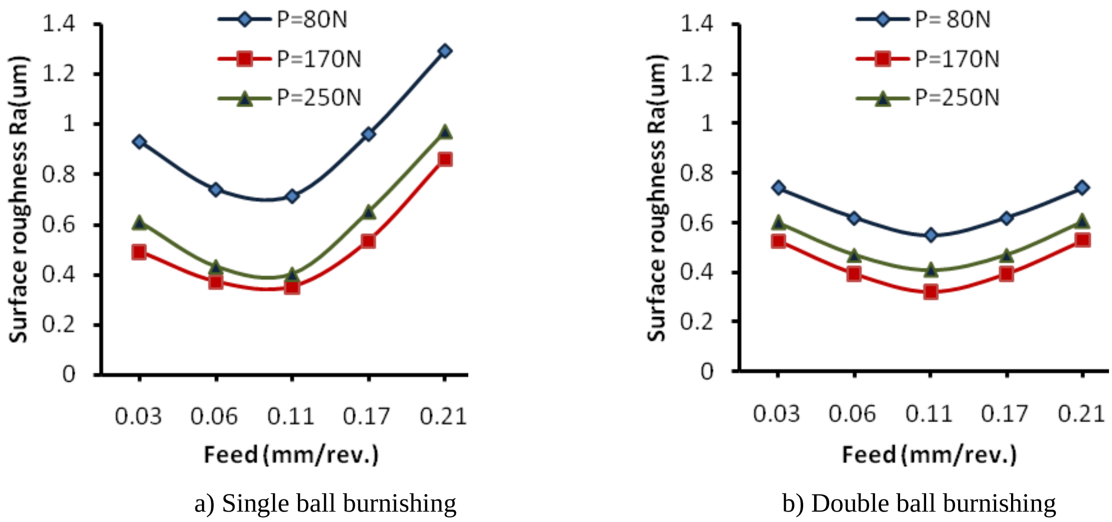


Fig. 5 Effect of burnishing feed on surface roughness for different burnishing force

The resulted surface roughness values in both figures are considerably reduced compared to machined surface roughness (Ra= 2.5 μm) i.e. before burnishing process, which gives the conclusion that the burnishing tool is effective. The trend of the relation between feed rate and the burnished surface roughness, as shown in fig. 5, are approximately the same for single and double ball burnishing. First the surface roughness slightly decreased as the feed rate increased. Then when feed rate increased above 0.11 mm/rev. the surface roughness was increased. To interpret the above phenomenon, a schematic representation of ball burnishing process is shown in fig. 6. This figure shows increasing of feed increasing the distance between the peaks which lead to increasing of surface roughness. Using of very low feed values caused reduction of area opposite to the tool which increased the compressive stress more which caused overhardning that may cause flaking for the surface and deteriorate the surface finish.

The minimum surface roughness was obtained with a burnishing force of 170 N, at a feed rate of 0.11 mm/rev. After this feed value the surface roughness increased as the feed rate increased. The maximum surface roughness values were obtained with a burnishing force of 80N. The improvement of surface roughness when increasing the force from 80N to 170N is expected as the increase of the force increase the depth of penetration resulting in compressing more asperities and increases the metal flow that leads to the filling of more valleys that were existed on subsurface due to the previous turning process [6].

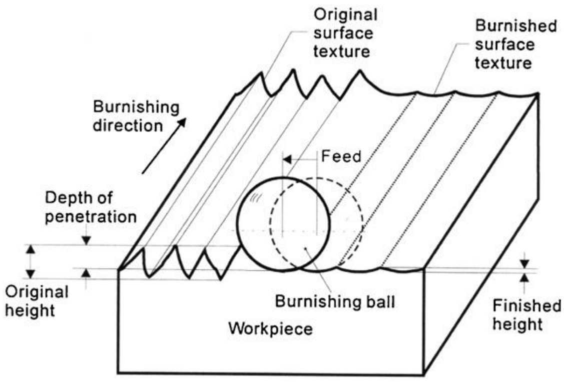


Fig. 6 Schematic representation of the ball burnishing process.

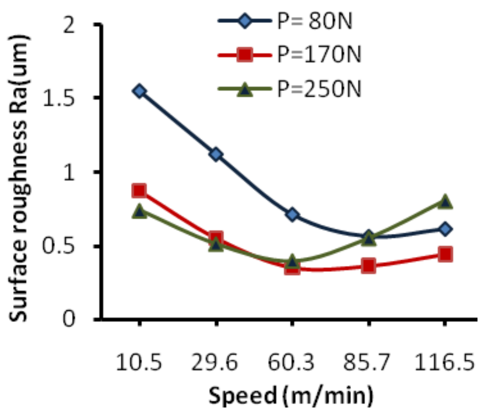
When the burnishing force increased from 170N to 250N the surface roughness was increased. This may be due to the overhardening and consequently flaking of the surface layer. The increase of force above a certain value (170N) also increases the bludge in front of burnishing ball and widens the region of plastic deformation which damages the burnished surface and increased the surface roughness. So there is an optimum burnished force that gives the best surface roughness. Mieczyshaw [7] reported that, the optimal value for burnishing force depends on the elastic-plastic properties of treated material and surface roughness obtained from previous machining process.

Fig. 5 also shows that, the best surface roughness can be obtained with double ball burnishing. This is true as the use of a single ball making the workpiese to be elastically deformed along its longitudinal direction under the action of the normal force. The use of a second ball in the same line with the first one but opposite in direction prevents this elastic deformation and prevents whirling of the workpiece which reduces vibration between the tool and workpiece causing a reduction in the obtained surface roughness values.

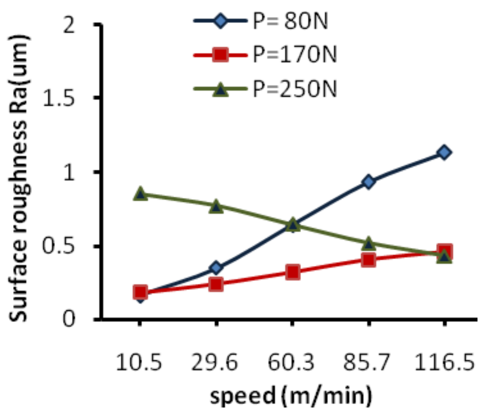
3.1.2 Effect of burnishing speed

The relations between burnishing speed and surface roughness are shown in figs. 7, 8. Fig. 7 shows the effect of burnishing speed on surface roughness at constant feed rate of 0.11mm/rev., under different burnishing forces. While fig. 8 shows this effect at constant force of 170N and at different feed rates. Referring to fig. 7a it can be noticed that, with a single ball the increasing of speed decreases the surface roughness for the force 80N, but for the forces 170N and 250N surface roughness first decreased with the increase of speed up to a speed of 60.3 m/min. then slightly increased for further increasing of speed. The rate of increasing with a force of 250N is higher than that with the force of 170N. This may partially, be due to chatter which is usually existed at high speeds with high forces. Fig. 7a also shows that, at low speeds the surface roughness is optimum at a force of 250N, while the worst one was obtained with a force of 80N. This can be attributed to the fact that, at low speeds the deformation action of the ball is high which deteriorates the surface roughness. In this case high force is required to press the peaks of the burnished surface. But at high speeds the reverse was true. Fig. 7a also shows that, the minimum surface roughness was obtained at a speed of 60.3 m/min. and burnishing force of =170N at 0.11 mm/rev. feed.

In situation where double balls were used for burnishing fig. 7b, it can be seen that, using low burnishing force (80N) the surface roughness is increased as the speed increased. The same result was obtained when using the force 170N but with a lower gradient. While with burnishing force of 250N the burnished surface roughness is reduced as the speed increase. It can be noticed from the figure also that, the range of variation of surface roughness for different speeds at the forces 170, and 250N is minimum than that of single ball burnishing. The use of a second ball as discussed before prevents this elastic deformation and prevents whirling of the workpiece which reduces vibration between the tool and workpiece causing minimization for the speed variation's effect on the existence of vibration between tool and workpiece. At low speed also (10.5 m/min.) the surface roughness for the force 250N is greater than other forces and this may be due to overhardnening caused for the workpiece surface under the action of this force.



a) Single ball burnishing



b) Double ball burnishing

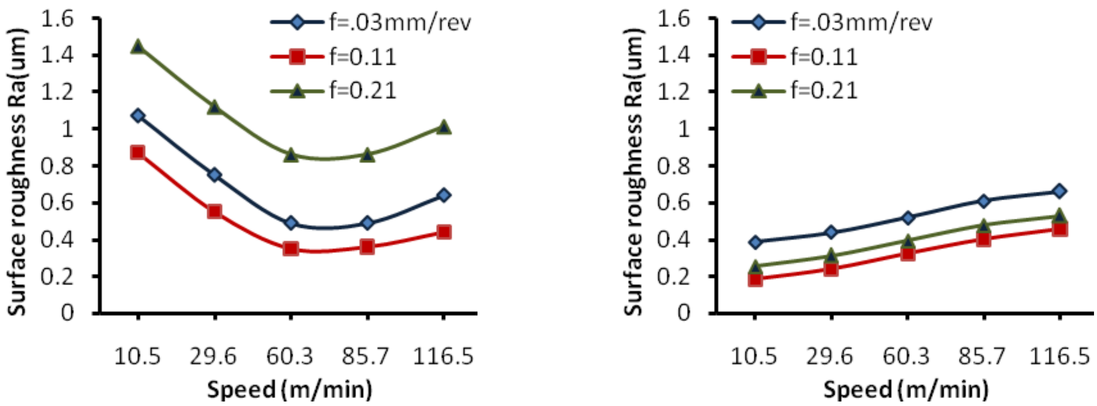
Fig. 7 Effect of burnishing speed on surface roughness at 0.11 mm/rev. Feed rate

It can be seen also from Fig. 7 that, the range of surface roughness obtained by double ball burnishing is less than that obtained by single ball burnishing. For double ball burnishing better surface roughness can be achieved using low values of forces with low speeds, or using high forces with high speeds.

Effect of burnishing speed on surface roughness at different feeds under constant burnishing force (170N) is shown in fig. 8. In case of single ball burnishing, the surface roughness decreases with the increase of burnishing speed until 60.3 m/min. speed and then slightly increases with the burnishing speed as shown in fig. 8a.

On the other hand, Fig. 8b shows that, the surface roughness increases with burnishing speed for different feeds using double ball burnishing. The deterioration of surface roughness with the increase of speeds is believable as the two balls guided the specimen without any permission for elastic deformation. This may cause the system to fall in chatter with the increase of speeds. At high speeds, there is also a lubricant loss due to insufficient time for it to penetrate between the ball and the burnished surface which is essential for double ball burnishing [8].

In general for single and double burnishing the minimum surface roughness can be achieved using 0.11 mm/rev. feed, and at a burnishing speed of 60.3 m/min. for single ball burnishing, and 10.5 m/min. for double ball burnishing.



a) Single ball burnishing b) Double ball burnishing

Fig. 8 Effect of burnishing speed on surface roughness at 170N burnishing force

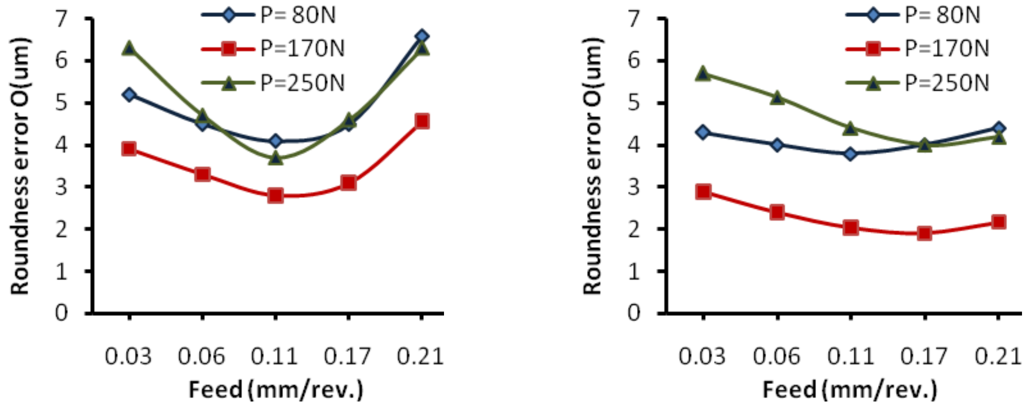
Fig. 8 also shows the ranges of surface roughness for double ball burnishing is smaller than that for single ball.

3.2 Effect of burnishing parameters on roundness error

Roundness error plays an important role in the efficiency of any mechanical component. This error could be due to deflection of the workpiece as a result of the forces generated during cutting. This may be also due to incorrect positioning or misalignment of the workpiece during machining. One of the objectives of this investigation is to study the effect of the used burnishing tool and burnishing parameters on improvement the machined surface roundness.

3.2.1 Effect of feed rate

Fig. 9 shows the effect of feed on the burnished surface roundness error for both burnishing methods. Fig. 9a shows, for single ball burnishing, that the increase of feed from 0.03 to 0.11mm/rev. reduces the roundness error. Hence further increase of feed above 0.11 mm/rev. increases roundness error. This can be explained by the fact that, at very low feeds the deformation action of the ball is accumulated due to its small axial movement that may cause shear of subsurface layer (flaking) leading to deterioration of roundness error. Increasing of roundness error beyond the feeds above 0.11 mm/rev. is expected due to the increase of axial distance moved by the tool during burnishing process. So, for single ball burnishing it is preferable to avoid burnishing at very low feeds as well as at very high feeds.



a) Single ball burnishing

b) Double ball burnishing

Fig. 9 Effect of burnishing feed on roundness error at 60.3m/min burnishing speed

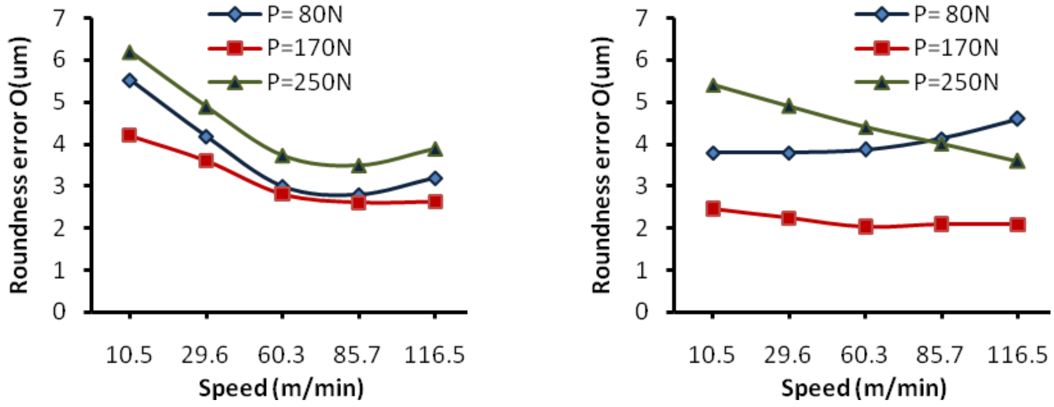
For double ball burnishing fig. 9b, the relation exhibited approximately the same trend as in fig. 9a for single ball burnishing. But the feed rate limit at which the roundness error begins to increase increased from 0.11mm/rev. (for single ball, fig. 9a), to 0.17 mm/rev. as shown in fig. 9b.

Fig. 9 also shows that the roundness error for double ball burnishing is smaller than that of single ball as the second ball supports the workpiece preventing its deflection under the acting forces which is the main cause of roundness error. The increase of force from 80N to 170N decreases roundness error. This is due to compressing more asperities on the burnished surface with the force of 170N. Further increase of the force to 250N increases roundness error because shear failure occurred for subsurface layer (flaking) under the action of this force, which in turn increases roundness error. This lead the manufacturer to give more attention for the value of burnishing force as it affects the result of burnishing process.

3.2.2 Effect of burnishing speed

Effect of burnishing speed on roundness error is shown in figs. 10, and 11. Fig. 10 was plotted to study the interaction between speed and force, while fig. 11 for the interaction between speed and feed. For single ball burnishing, fig. 10a, the increase of speed reduce roundness error for all of burnishing forces levels. Figure 10b shows that at low force of 80N, the increase of speed increased roundness error for double ball burnishing.

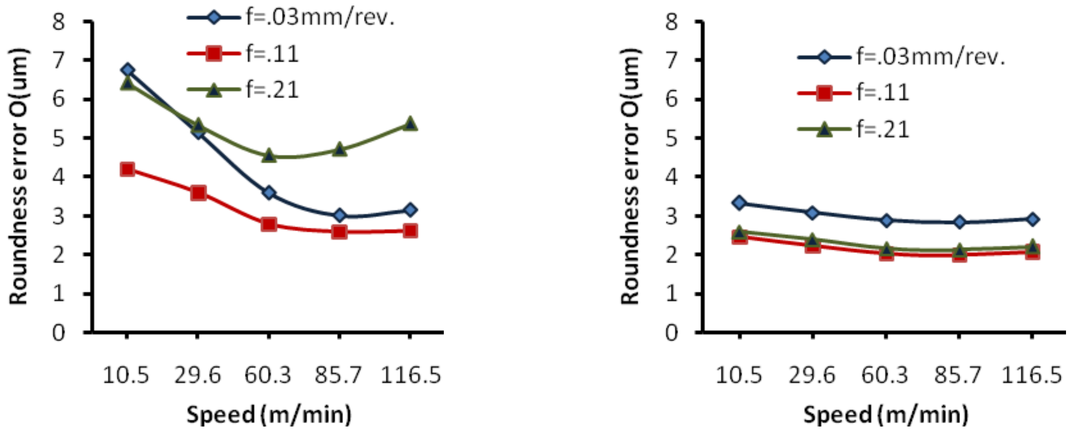
Fig. 10 also shows the best result of roundness error was obtained with double ball burnishing by using burnishing force of 170N.



a) Single ball burnishing b) Double ball burnishing

Fig. 10 Effect of burnishing speed on roundness error at 0.11mm/rev. feed rate

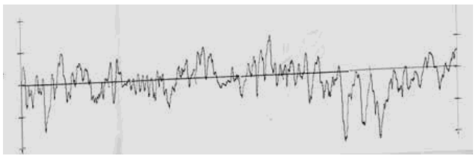
Fig. 11 shows the effect of burnishing speed at various feed rates. As shown in the figure for all feeds values, roundness error is decreased as the speed increased except for single ball burnishing at feed of 0.21mmm/rev.. In this case the increase of speed above 60.3 m/min. increased roundness error. This may be due to, the increase of built up material ahead of the ball, leading to excessive vibration which deteriorate the roundness error.



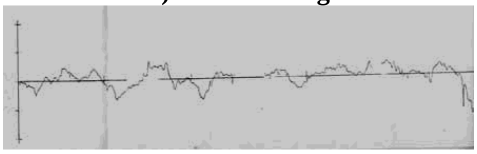
a) Single ball burnishing b) Double ball burnishing

Fig. 11 Effect of burnishing speed on roundness error at 170N burnishing force

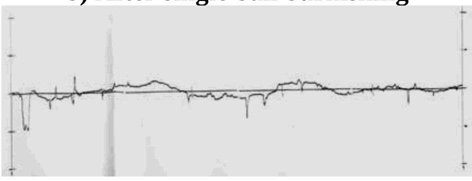
Figs. 10, and 11 also show that the best result of roundness error was obtained with double ball burnishing while using burnishing force of 170N. The small roundness error also can be achieved by using burnishing speeds between 60.3, and 85.7 m/min. with a burnishing feed of 0.11 mm/rev.



a) After turning



b) After single ball burnishing



c) After double ball burnishing

Fig. 12 Surface roughness profile

The surface roughness profile for the specimen burnished with feed= 0.11 mm/rev., speed = 60.3 m/min., and a force of 170N is displayed in fig. 12 before burnishing after turning, and after burnishing with single, and double burnishing. This figure clarifies the effectiveness of the burnishing tool, and also the ability of double burnishing in producing smooth surfaces than single burnishing.

4. CONCLUSIONS

A new burnishing tool was introduced in this investigation which enables both single and double ball burnishing process in site after turning without releasing the workpiece. Effect of burnishing parameters upon final surface texture (roughness and roundness) was demonstrated.

- Burnishing results showed that, the burnishing tool has a significant improvement of the surfaces resulted from the process. The surface roughness and roundness error of the turned test specimens were improved by burnishing from about Ra = 2.5 to about 0.2 µm, and roundness error from about 7.3 to about 2 µm.
- For the treated material in this investigation the optimal value for burnishing force that gave best surface roughness and roundness error was 170N.
- The minimum surface roughness was obtained at a feed rate 0.11 mm/rev. and a speed of 60.3 m/min
- For double ball burnishing better surface roughness can be achieved using low values of forces with low speeds, or using high forces with high speeds.
- The best results of surface roughness and roundness error were obtained with double ball burnishing using burnishing force of 170N. The small roundness error can also be achieved by using burnishing speeds between 60.3, and 85.7 m/min. with a burnishing feed of 0.11 mm/rev.

- For single ball burnishing it is preferable to avoid burnishing at very low feeds as well as very high feeds.

REFERENCES

1] Yu, X., Wang, L., "Effect of various parameters on the surface roughness of an aluminum alloy burnished with a spherical surfaced polycrystalline diamond tool", Int. J. Mach. Tools Manuf. 39, pp(459–469), 1999.

2] Mamalis, A.G., Grabchenko, A.I., Horv ´ ath, M., M ´ esz ´ aros, I., Paulmier, D., "Ultraprecision metal removal processing of mirror-surfaces", J. Mater. Process. Technol. 108, pp(269–277), 2001.

3] Shiou, F.J., Chen, C.C.A., Li, W.T., "Automated surface finishing of plastic injection mould steel with spherical grinding and ball burnishing processes". Int. J. Adv. Manuf. Technol. 28, pp(61–66), 2003.

4] Luca, L., Neagu-Ventzel, S., Marinescu, I., "Effects of working parameters on surface finish in ball-burnishing of hardened steels", Precis. Eng. 29, pp(253–256), 2005.

5] Fang-Jung Shiou, Chih-Cheng Hsu "Surface finishing of hardened and tempered stainless tool steel using sequential ball grinding, ball burnishing and ball polishing processes on a machining centre" journal of materials processing technology 205, pp(249–258), 2008.

6] M.H. El-Axir, M.M. El-Khabeery "Influence of orthogonal burnishing parameters on surface characteristics for various materials" Journal of Materials Processing Technology 132, pp(82–89), 2003.

7] Mieczystaw Korzynski, "Modeling and experimental validation of the force–surface roughness relation for smoothing burnishing with a spherical tool", International Journal of Machine Tools & Manufacture 47 pp(1956–1964), 2007.

8] El-Axir, M. H., and Ibrahim, A. A., "Some surface characteristics due to center rest ball burnishing" J. Materials Processing Technology. 167(1),pp(47-53.) , 2005.