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Center rest balls burnishing parameters adaptation of steel components using fuzzy logic

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ABSTRACT

The present work deals with the control of ball burnishing parameters of steel components via fuzzy logic. This burnishing tool using three balls is designed and constructed in such a way as to replace the three original adjustable jaws of the center rest. The center rest and the lathe saddle were clamped together to operate as one piece.

Experimental work was conducted on a lathe to study the effect of burnishing parameters (feed, speed, force, and number of balls used in single pass) on surface characteristics (surface roundness error). Experimental results from this work were used as a knowledge base to prepare a fuzzy logic model to control burnishing parameters.

The results obtained from the experimental work and fuzzy model showed that good surface characteristics can be achieved by using this center rest ball burnishing tool. Burnishing force, burnishing feed and number of balls in single pass are the most important parameters that play an important role in controlling the values of all surface characteristics. The results obtained from the fuzzy model are highly consistent with experimental results.

1. Introduction

Ball burnishing shown in Fig. 1 is a process where a tool, with a free rotating ball, presses against the surface of a part which plastically deforms the micro peaks into the micro valleys of the surface as shown in Fig. 2. Ball burnishing, a cold forming process, is usually applied after one or many machining processes. Extremely good surface finishes and good dimensional integrity can be achieved using ball burnishing (Roettger, 2002).

A literature survey shows that work on the burnishing process has been conducted by many researchers and the process improves the properties of the machined parts. El-Axir and Ibrahim (2005) introduced a new burnishing tool. They used the center rest of a lathe as ball burnishing tool. The result of their investigation showed that the surface characteristics were improved with this burnishing tool. The surface roughness was also improved and surface hardness was increased using roller-burnishing tool (El-Axir, 2000). At the same time the use of milling roller burnishing increased surface hardness of the machined components (El-Khabeery and El-Axir, 2001). The process also increased maximum residual stress in compression (Klocke and Liermamnn, 1998). Burnishing had also decreased the roundness error of the specimens (El-Axir and El-Khabeery, 2003). A fuzzy model was used to achieve the optimum burnishing parameters for non-ferrous components (Dweiri et al., 2003).

Loh et al. (1989) reported that, ball burnishing parameters have an influence on surface hardness of the burnished component. These parameters also influenced burnished

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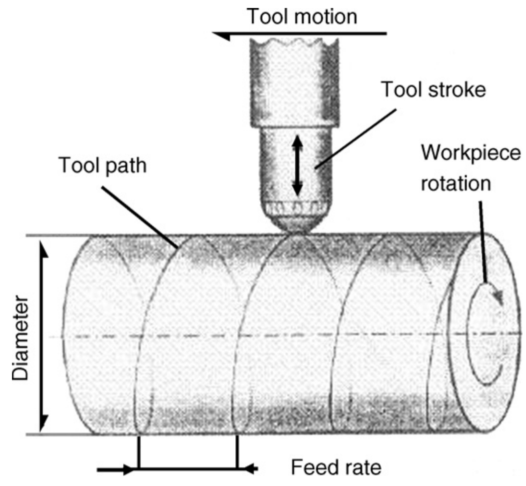

Fig. 1 – Ball burnishing process.

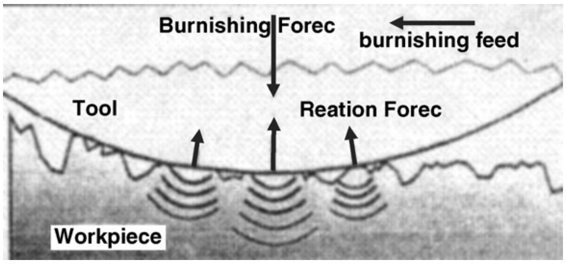

Fig. 2 – Micro peaks and valleys of the surface.

surface wear resistance (Yashcheritsyn et al., 1987). Burnishing process as well has an influence on microstructure of the burnished components (Hassan and Al-Bsharat, 1996). The parameters affecting the surface finish are: burnishing force, feed, ball or roller material, number of passes, workpiece material, and lubrication (El-Axir, 2000).

The effect of the process on specimens of different materials was studied by many authors, Lee et al. (1993) reported that, the surface of 316l stainless steel was improved by ball burnishing process. The surface finish of brass components also was improved by optimizing the number of ball passes with the burnishing force (Hassan et al., 1998). Wear resistance and adhesive wear resistance of the brass components were also increased by burnishing processes (Hassan and Sulieman, 1999). The process also increased the adhesive wear resistance of an electrically conductive polyester–carbon film (Michael et al., 1998).

To study the effect of burnishing process on the specimen's characteristics as well as to optimize the process parameters, models for the process were effective tools. Mieczyslaw (2007), proposed a model of burnishing using a spherical tool and studied the force–surface roughness relation. Fuzzy model is considered as the most effective model for optimization of machining parameters for economical machining process (Liu, 2004). It was used before for roundness error compensation in turning process (Ibrahim and Abd Rabbo, 2004), and to compensate roundness error in cylindrical plunge grinding (Ibrahim et al., 2003). A fuzzy model was used to achieve the optimum burnishing parameters for non-ferrous components (Dweiri et al., 2003).

The present paper examines the use of a ball burnishing tool (moving rest burnishing tool) to give good surface characteristic such as, higher surface finish and lesser out-of-roundness. The effects of three burnishing parameters namely, burnishing speed, feed, and burnishing force on out-of-roundness are studied through this work. Experimental results were used as a knowledge base to prepare a fuzzy logic model which controls burnishing parameters.

2. Experimental work

2.1. *Workpiece material*

In this work, mild steel was used as a workpiece material. The chemical composition and mechanical properties of the material are as shown in Table 1.

This material was selected because of its importance in industry and its susceptibility to degradation when burnished, through surface and subsurface damage.

Table 1 – Chemical composition and mechanical properties of workpiece

%C	%S	%Mn	%P	%S	σ_U (N/cm^2)	σ_Y (N/cm^2)	B.H.N.
0.25	0.25	0.55	0.045	0.045	450	230	130

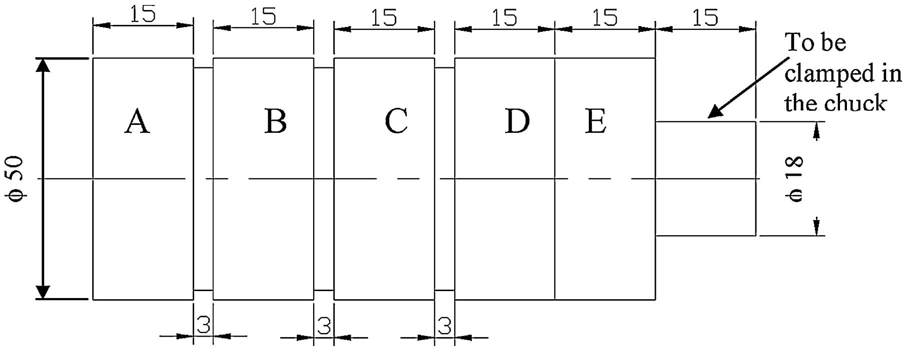

Fig. 3 – Workpiece geometry and dimensions in mm.

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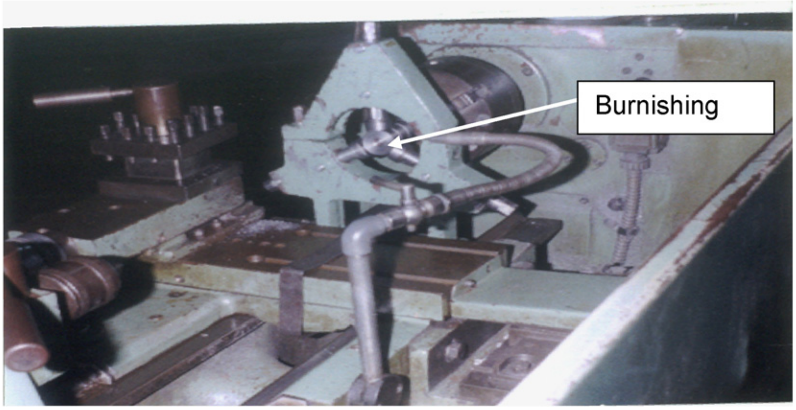

(a) A specimen attached to the chuck and center rest burnishing tool

(b) Burnishing tool

Fig. 4 – Burnishing tool and its attachment to the center rest.

2.2. *Workpiece preparation*

The material was received in the form of solid bars that was machined into workpieces having the dimensions shown in Fig. 3. The workpieces were prepared with three recesses such that each specimen could be used in three different conditions to study the effect of the number of balls which were used during burnishing using the center rest burnishing tool; one ball (part A), two balls (part B), three balls (part C) furthermore a portion D was left without burnishing for comparison purposes with portions A, B and C. Part E which is shown in the figure is a safety length to avoid the impact of the rest with the chuck.

Fig. 4a shows a specimen attached to the chuck and the center rest burnishing tool constructed to achieve the aim of this work. While Fig. 4b shows one burnishing tool of three balls which is designed and constructed to replace the three original adjustable jaws of the steady rest.

As shown in the figure each burnishing tool is ended with a hexagonal nut. By tightening this nut with torque arm wrench, variable burnishing forces were obtained. Also, burnishing with one, two, or three balls was applied by disabling one or two of these tools.

The center rest was clamped with the lathe saddle to move with it as one part and then variable feed rates for burnishing were applied by the lathe saddle.

2.3. *Burnishing conditions*

In this work, external moving rest ball burnishing tests were performed. All the burnishing tests were performed under lubricated conditions. Lubrication was performed using the ordinary lathe cooling system. Only three burnishing parameters were chosen namely, burnishing speed (V), burnishing force (F), and feed (f), also other parameters such as ball diameter and lubrication were held constant throughout the work. Since dry burnishing conditions produced poor surface finish, it was decided to apply a suitable lubricant during all tests which was emulation-type soluble oil mixed with water. Also, constant ball diameters each of 10 mm, were used throughout this investigation. The burnishing conditions are summarized in Table 2.

Table 2 – Summary of burnishing conditions range

Burnishing speed (m/s)	0.159–1.84
Burnishing force (N)	70–230
Burnishing feed (mm/rev)	0.04–0.19
Ball diameter (mm)	10
Burnishing conditions	Lubricated

2.4. *Measurements*

In this work, the produced surface roughness, change in workpiece diameter, and out-of-roundness were carefully measured using standard techniques. Different burnishing forces were applied using the torque arm key. Different feeds were also applied using lathe feeds, as the center rest was clamped to move with the lathe saddle as one part.

2.4.1. *Surface out-of-roundness*

A roundness error is considered as one of the important geometrical errors for cylindrical components because it has negative effects on accuracy and other important factors such as wears in rotating elements. Also, it is well known that only plastic deformation takes place in the surface during the burnishing process, which, in turn, causes variation in the produced roundness. Therefore, surface roundness before and after burnishing was measured using ROUNDTEST RA-112-122. For better results the arithmetic average of three readings has been calculated.

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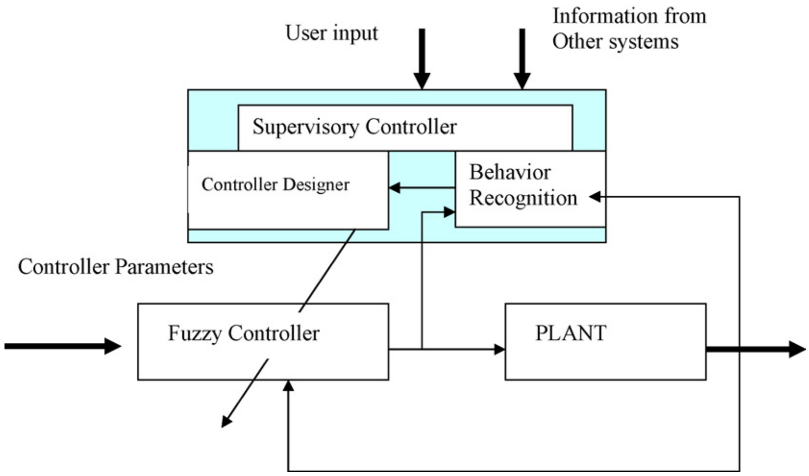

Fig. 5 – Structure of self-organizing fuzzy logic controller.

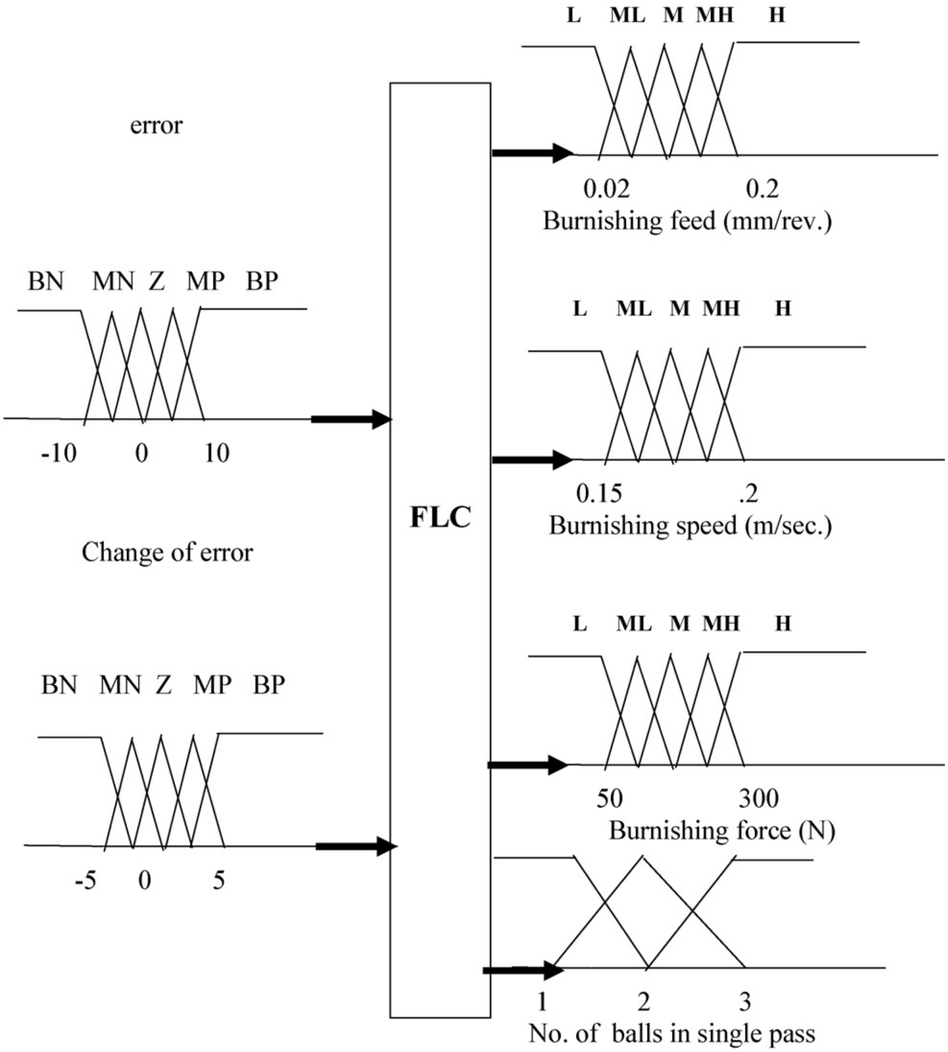

Fig. 6 – Fuzzy logic system for burnishing process.

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Table 3 – Rule base for feed, speed, and force

	BN	MN	Z	MP	BP
BN Big Negative	L	ML	M	MH	H
MN Medium Negative	ML	ML	M	MH	MH
Z Zero	M	M	M	M	M
MP Medium Positive	MH	MH	M	ML	ML
BP Big Positive	H	MH	M	ML	L

Where, L: low, ML: medium low, M: medium, MH: medium high, and H: high.

Table 4 – Rule base for number of burnishing ball in single pass

	BN	MN	Z	MP	BP
BN	3	3	3	1	1
MN	3	3	3	1	1
Z	3	3	3	3	3
MP	1	1	3	3	3
BP	1	1	3	3	3

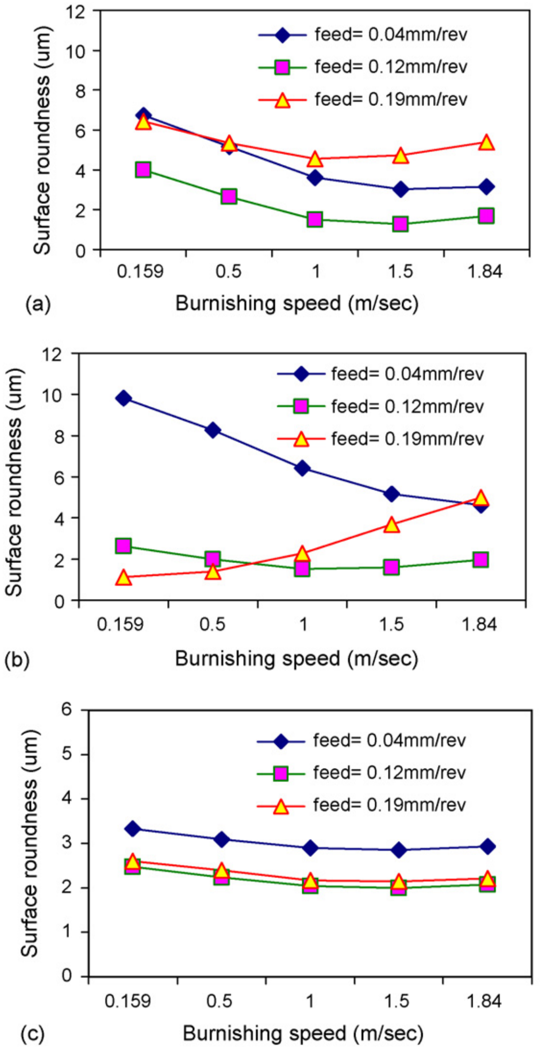

Fig. 7 – (a) Effect of burnishing speed on surface roundness at different feeds (one ball pass); (b) effect of burnishing speed on surface roundness at different feeds (two balls pass); (c) effect of burnishing speed on surface roundness at different feeds (three balls pass).

3. Self-organising fuzzy logic controller (SOFLC)

Self-organizing fuzzy logic controller extends the standard fuzzy logic controller by incorporating performance feedback in the basic fuzzy logic controller. SOFLC is also a performance adaptive fuzzy knowledge base controller. However, in this case the rules, not the fuzzy set definition or the scaling factor, are adapted. The structure of the controller is similar, but this time, it also includes a model of the process (Ibrahim and Abd Rabbo, 2004). A block diagram is given in Fig. 5. The controller is a standard Multi-Input Multi-Output (MIMO), with the error (e) and change in error (Δe) as inputs. The output control actions are speed, feed, burnishing force and the number of burnishing balls in single pass. In order to design a self-organizing fuzzy logic controller, the following steps must be performed.

1. Development of suitable sets.
2. Selection of input/output variables and their quantification in fuzzy sets.
3. Definition of membership functions to be associated with the input/output variables.
4. Selection of the defuzzification technique.

3.1. *Membership functions*

SOFLC is applying to control the error in out-of-roundness. The inputs are the errors (e), and change error (Δe), while the outputs are burnishing speed, burnishing feed, burnishing force, and the number of burnishing balls in a single pass. The universe of discourse of error (e) is defined on the interval [−10 to 10] and change in error (Δe) is defined on the interval [−5 to 5]. The outputs feed, speed, force and the number of balls in single pass are defined on the interval [0.02–0.2], [0.15–2], [50–300], and [1–3] simultaneously as shown in Fig. 6.

Tables 3 and 4 illustrate the rule base of fuzzy controller in tabular form, the cells defined by the intersection of rows and columns represent a rule such as

IF $e(k)$ is Zero and $\Delta e(k)$ is Z
THEN then burnishing feed is medium AND
burnishing speed is medium AND
burnishing force is medium AND
burnishing number of balls in a single pass is3

The implied fuzzy set is transformed to a crisp output by the center of gravity defuzzification technique as given by the formula.

$$Z = \frac{\sum_{i=1}^{i=n} Z_i \mu(Z_i)}{\sum_{i=1}^{i=n} \mu(Z_i)} \tag{1}$$

where Z_i is the numerical output at the ith number of rules; $\mu(Z_i)$ corresponds to the value of fuzzy membership function

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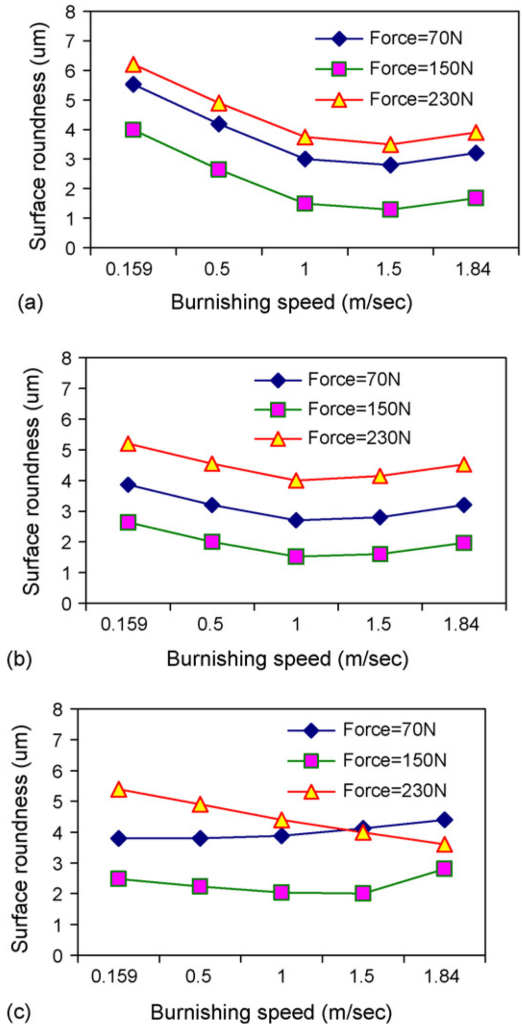

Fig. 8 – (a) Effect of burnishing speed on surface roundness at different forces (one ball pass); (b) effect of burnishing speed on surface roundness at different forces (two balls pass); (c) effect of burnishing speed on surface roundness at different forces (three balls pass).

at the ith number of rules; *n*: is the number of rules that apply for the given fuzzy inputs.

4. Results and discussion

To study and discuss the effect of the input parameters on the three different responses, Figs. 7–9 are constructed showing the results of the effect of burnishing conditions in the cases of one ball, two balls with lines of action at 120°, and three balls with lines of action at 120° on the response with the same burnishing conditions on the same figure. It should be pointed out here that in the case of burnishing force, it was found that the results of 70 and 100 N and also of 200 and 230 N were very close. Therefore, only three levels of burnishing force (70, 150 and 230 N) were presented in each figure.

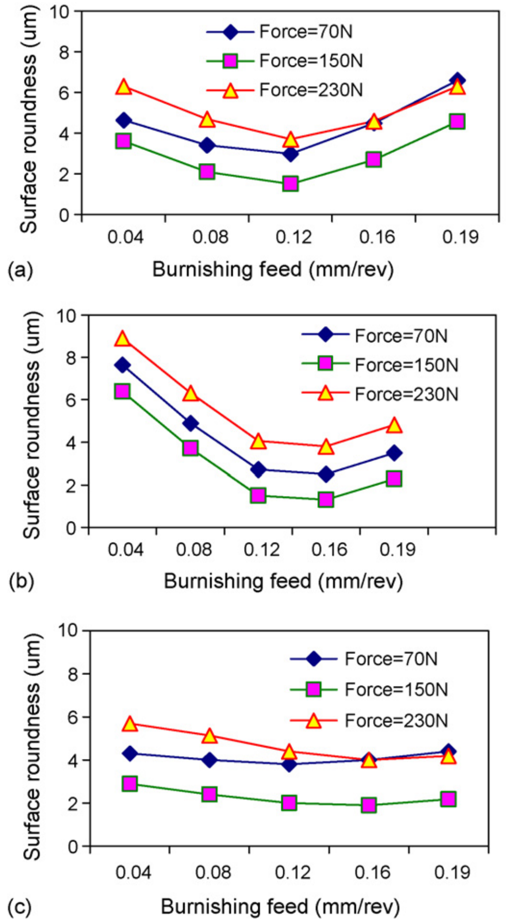

Fig. 9 – (a) Effect of burnishing feed on surface roundness at different forces (one ball pass); (b) effect of burnishing feed on surface roundness at different forces (two balls pass); (c) effect of burnishing feed on surface roundness at different forces (three balls pass).

4.1. *Experimental results*

4.1.1. *Burnishing speed*

The effect of burnishing speed on the variation of out-of-roundness can be assessed from Figs. 7 and 8. From these figures, it can be seen that in the case of using one ball, as the burnishing speed increases, the out-of-roundness decreases at any value of feed and/or force. However, in the case of two balls, there is an interaction between burnishing speed and feed. At low feed, an increase in burnishing speed leads to a decrease in the out-of-roundness whereas at highest feed the out-of-roundness increases with an increase in burnishing speed.

4.1.2. *Burnishing feed*

Figs. 7 and 9 present the effect of the burnishing feed on the burnished surface roundness at various speeds and forces, respectively. It can generally be seen that out-of-roundness decreases with an increase in burnishing feed, reaching a minimum value at a burnishing feed of 0.12 mm/rev. A further increase in feed more than 0.12 mm/rev causes a slight increase in surface out-of-roundness. From the results of these

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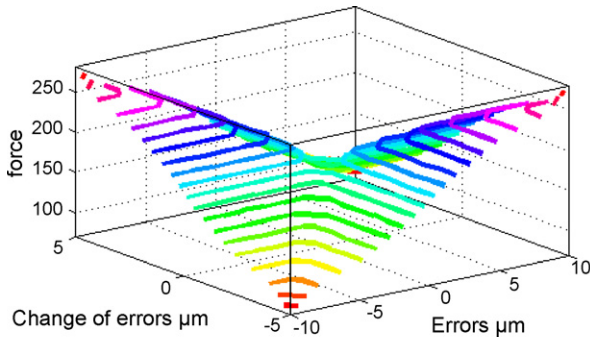

Fig. 10 – Fuzzy surface representation of roundness error, roundness change of errors, and burnishing force (N).

two figures it is clear that, it is preferable to avoid burnishing at very low feeds. This is because at very low feed the deforming action of the balls is so high that flaking occurs.

4.1.3. *Burnishing force*

Burnishing force is one of the very important burnishing parameters that affect the results of this process. The increase in burnishing force causes increase in the amount of surface deformation as the tool passes along the surface of the workpiece. This will lead to an increase in the homogeneity of the surface layers, which have been affected by plastic deformation, so that out-of-roundness will improve (decrease) via increase in burnishing force up to 150 N, as shown in Figs. 8 and 9. The out-of-roundness of the burnished surface decreased as burnishing force increased as a result of the regularity of the metal flow on the burnished surface from 70 to 150 N. However, the results show that burnishing mild steel with forces more than 150 N, the surface roundness is deteriorated. This may be due to high forces that cause shear failure in the subsurface layers which, in turn, results in the flaking.

4.2. *Fuzzy results*

Fig. 10 shows fuzzy surface representation of roundness error and roundness change of errors, versus burnishing force. The out-of-roundness of the burnished surface decrease to minimum value up to a force of 150 N and begins to increase with the increase of burnishing force at more than 150 N, and the surface roundness is deteriorated. Fig. 11 presents the fuzzy surface representation of the burnishing feed versus burnished surface roundness errors and change of errors. Burnishing feeds of 0.12 mm/rev. represent the minimum value, further increase in feed causes a slight increase in surface roundness errors. As depicted in Fig. 12 a speed of 1.1 m/s. shows a minimum surface out-of-roundness. Finally Fig. 13

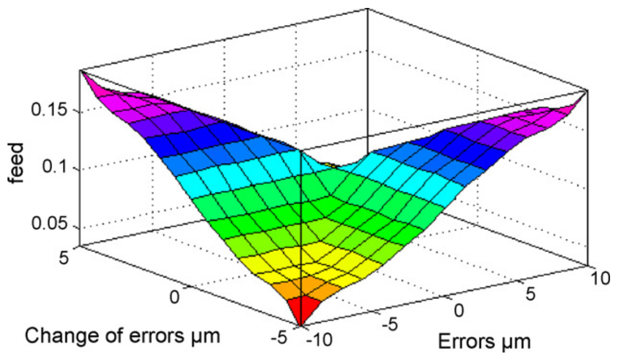

Fig. 11 – Fuzzy surface representation of roundness error, roundness change of errors, and burnishing feed (mm/rev.).

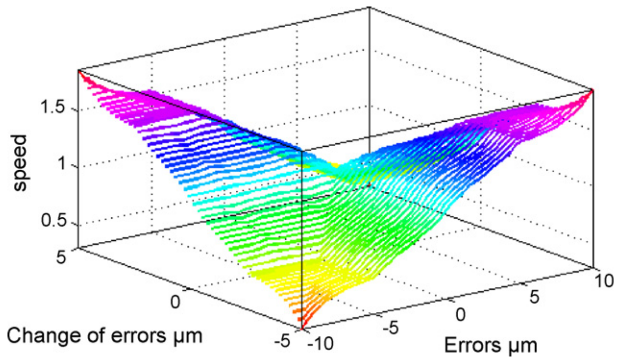

Fig. 12 – Fuzzy surface representation of roundness error, roundness change of errors, and burnishing speed (m/s.).

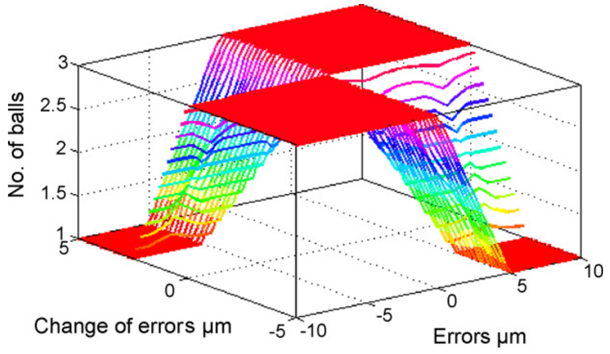

Fig. 13 – Fuzzy surface representation of roundness error, roundness change of errors, and number of burnishing balls.

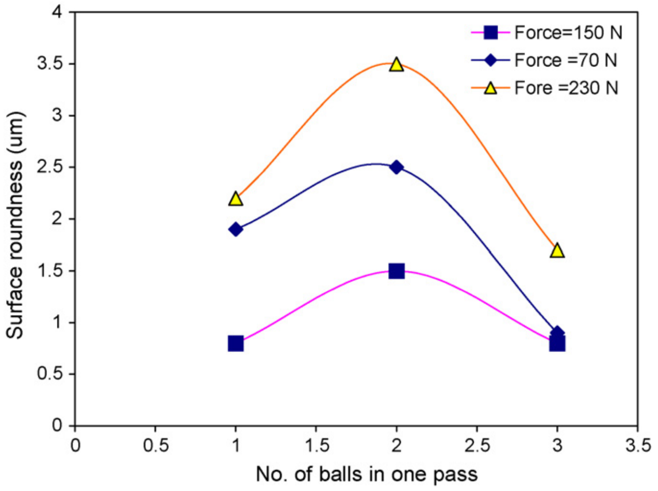

Fig. 14 – Effect of number of balls in one pass on surface roundness at different burnishing forces (feed 0.12 mm/rev. and speed 1.25 m/s).

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illustrates that the use of three balls is the most dominant, and Fig. 14 shows the effect of burnishing balls on surface roundness errors at different forces.

The best results can be obtained at a combination of burnishing speed of 1 m/s with burnishing feed of 0.12 mm/rev. and burnishing force of 150 N. Also, the obtained results of out-of-roundness applying the moving rest burnishing with three balls are the best.

5. Conclusion

In this investigation the moving rest was used as a superfinishing tool by replacing the three original adjustable jaws of the moving rest with three balls in the burnishing tool. The effects of burnishing parameters using this new tool were studied. Experimental results from this work were used as a knowledge base for a fuzzy logic model which controls the burnishing parameters. The results obtained from the fuzzy model are highly consistent with experimental results. The following can be concluded from experimental and fuzzy model:

1. The output responses of the burnished surface using the moving rest ball burnishing are mainly influenced by the used parameters. The burnishing force, burnishing speed, burnishing feed, and the number of balls in one pass were used as the control actions for the fuzzy controller.
2. Experimental and fuzzy results showed that an increase in burnishing speed up to 1.5 m/s leads to a decrease in the burnished out-of-roundness whereas the increase in burnishing speed more than 1.5m/sec results in an increase in out-of-roundness.
3. An increase in burnishing feed up to 0.12 mm/rev leads to a decrease in all responses studied in this work. The best results for roundness obtained at burnishing force of 150 N and burnishing feed of 0.12 m/rev.
4. Good results for all responses studied in this work can be obtained using the moving rest burnishing tool applying one ball or three balls.

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