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Improving the Surface Finish of Concave and Convex Surfaces Using a Ball Burnishing Process

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Improving the Surface Finish of Concave and Convex Surfaces Using a Ball Burnishing Process

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The ball burnishing process is done to improve the surface finish of workpieces that have been previously machined. In this article we present the results of tests performed with this process that was applied to workpieces with a convex or concave surface of two different materials: aluminum A92017 and steel G10380. An experiment to do the tests was designed. The results of measurements of surface roughness are presented in this paper as well. These results are compared to those measured in the workpieces before being burnished. After that conclusions are drawn about the improvement of surface roughness applied to the workpieces through the ball burnishing process. The main innovation of this paper is that we work with concave and convex geometries. We also obtain a table of recomended parameter values for the process.

Keywords Burnishing; Manufacturing; Roughness; Surface.

Introduction

A good surface finish on a complex surface geometry, for instance, any part of a three-dimensional (3D) mold or die is a very difficult problem to be solved. A flat or revolution surface can be produced relatively easily in a grinding machine; thereby, improving its finish is relatively simple. When the development surface is complex, improving its quality is not that simple and that is when this process is a problem.

In this case we have developed a study to improve the surface finish of concave and convex configurations through a ball burnishing process developed in the same milling machine in which the workpiece in question has been developed.

Through a ball burnishing operation complex configuration surfaces could be machined to obtain a good surface finish on them, according to Yen et al. [1]. As shown in Fig. 1, this process is developed using a tool that is mounted on a hydraulic head, which will apply some pressure to a ball. When this ball glides on the workpiece area, it deforms the peaks of the surface irregularities, flattening the surface profile, and producing a much more regular surface than the one that the workpiece had before.

To perform this study, a series of experiments will de developed. The system parameters will vary between three values. The impact of this variation on the results of measured surface roughness is obtained, as well as their best values.

A ball burnishing process is recommended because the tool can be easily installed on the same computer numerical control (CNC) machine. The ball can have diameters between 3 and 12 mm, and it operates under the action of a normal force high enough to deform the peaks of the surface profile to be treated. The ball is in contact with the surface just for burnishing it, but it can freely rotate on itself, because the values of friction forces are very small. As it happens in the cutting process, plastic deformation is produced on the entire surface because the tool is constantly impacting on the workpiece according to Roettger [2], Klocke and Liermann [3], Prevey et al. [4], Nemat and Lyons [5], and Yen and Altan [6].

The ball burnishing is considered by Adel and Sulieman [7] as a cold working process, which can be used to improve the surface characteristics. According to these authors, most papers which have been published before refer to the effects of burnishing process on surface roughness and hardness. But they considered that it has not been worked enough to prove it. That is why their work was focused on evaluating the increased wear resistance when a burnishing operation is performed.

The same results of previous authors were obtained by Adel and Ayman [8] by applying different forces to bronze workpieces with different initial roughness. The force increase reduced the roughness of the burnished surface.

A study of the burnishing process in hard steel workpieces crafted in a lathe machine was developed by Luca [9]. Finite elements method (FEM) was used to develop models to predict the surface behavior in terms of surface finish after the burnishing process.

Four burnishing parameters, such as ball material, lateral pass width, force, and tool feed-rate, were selected by Fang-Jung and Chien-Hua [10] as factors of Taguchi experimental design to determine the optimal burnishing parameters which have the main influence on surface roughness. The optimal values of burnishing parameters were obtained

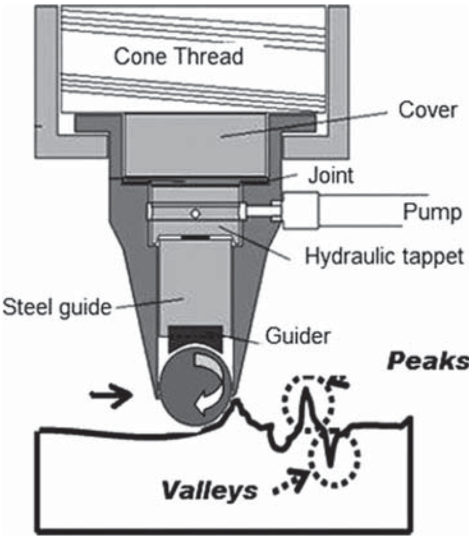

FIGURE 1.—Schematic representation of the ball burnishing process.

after performing the experiments. The parameters values were: the tungsten carbide ball, the 200 mm/min feed-rate, the 300 N burnishing force, and the 40 μm depth of burnishing. The surface roughness *Ra* of the sample was improved by about 1 to 0.07 μm by using the optimal parameters for flat burnishing.

One year later, Yen et al. [1] developed a research that focused on the processes of surface finish in a lathe machine. First, the conventional finish through a lathing process and second through a burnishing process. The most critical aspects that determine the surface final state and its properties such as residual stress, microstructure, and microhardness, were obtained. He also developed two models, two-dimensional (2D) and 3D to optimize the selection of burnishing process parameters (ball diameter, pressure, feed-rate), by using FEM, which were subsequently evaluated with experimental data.

More recently Hamadache et al. [11] shown that the hardness increase is reduced with an increase of the ball rotation frequency and feed-rate in the burnishing process, while the burnishing force as well as the number of passes increase the hardness.

As a last reference recently found, Celaya et al. [12] published a paper that is of great interest to develop a model of the burnishing process to obtain the required results in terms of surface finish and residual stresses in workpieces. This model can help to evaluate the effect of different operating parameters in the burnishing process. In this case, they evaluate a burnishing process of a revolution surface, but taking into account the parallel plane to the cylinder axis.

Most of the research papers, as it can be seen, focused on experimental tests in flat or revolution workpieces. Of course, the burnishing process is shown to be effective to improve the surface quality of these kinds of workpieces. The main advantage is the fact that it is performed in the same machine-tool in which the workpiece has been machined without removing it but avoiding the centering problems that occur if it is necessary to change the workpiece from one machine to another. It also helps to reduce manufacturing. In addition, in complex surfaces, the burnishing process can be convenient because normally their surface finish is only performed manually and in difficult conditions. For this reason, the main purpose and innovation of this article is to analyze how the process parameters influence on the surface quality of burnished convex and concave surfaces of two different materials (aluminium A92017 and steel G10380) and also to make recommendations about their optimal values to be used in this process.

EXPERIMENTS

Different experiments were performed on workpieces with convex and concave surfaces of two different materials: the aluminium A92017 and the steel G10380. The workpieces have the shape of Fig. 2. Convex or concave surfaces of the workpieces are composed of three areas in which there are three curves of 50, 100, and 50 mm of diameter, respectively. These curves have been machined by using different spherical mills with different diameters, but as a starting condition for each milling operation, the resulting peak height has been considered as a constant parameter.

On each milled area, the burnishing operation is performed. This operation is done every time with three different feed-rates. It means that in each burnished area we can find three subareas in which the difference lies in the values of feed-rates used.

In this case, the system parameters or variables to be evaluated are: the curvature radius of the burnished surface *r*, the feed-rate of the burnishing tool *a*, and the machining strategy that changes when the burnishing direction is changed, *D*. This direction can be parallel (Par) or perpendicular (Per) to the direction of the feed-rate of the milling process.

A 2^3 experimental design is obtained through these evaluation parameters, it means 8 combinations with two replicates, which makes a total of 16 different experiments in each case. The results of variable are shown in Tables 1 to 4. Regarding the results of the measurements four indicators of surface roughness have been taken into account: *Ra* (average surface roughness) and *Rt* (peak-valley maximal surface roughness), and both in the parallel direction of tool feed-rate (*Ra //* and *Rt //*) and in the perpendicular direction to the tool feed-rate ($Ra \perp$ and $Rt\perp$). Four equations are obtained, each one corresponding to each measured value.

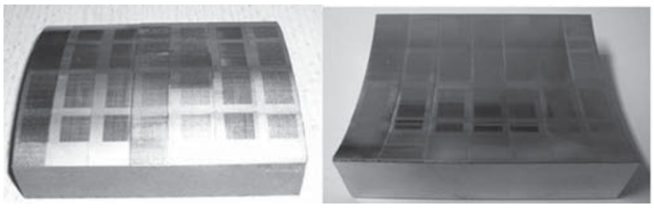

FIGURE 2.—Workpieces used for testing surface roughness after burnishing.

Table 1.—Results of roughness measurements in convex aluminium workpieces.

Exp. number	*r* (mm)	*a* (mm/min)	*D*	*Ra* // (μm)	*Rt* // (μm)	*Ra* ⊥ (μm)	*Rt* ⊥ (μm)
1	50	200	Par	0.0712	1.2291	0.5444	2.4399
2	100	200	Par	0.3441	3.8418	0.3081	1.7671
3	50	500	Par	0.0925	1.1649	0.4573	2.0082
4	100	500	Par	0.1619	2.5495	0.2925	1.5053
5	50	200	Per	0.1353	1.4762	0.3875	2.2829
6	100	200	Per	0.1987	1.8568	1.1473	4.6075
7	50	500	Per	0.1921	1.2336	0.0926	0.7101
8	100	500	Per	0.1933	1.3900	0.1511	0.9595
9	50	200	Par	0.0657	0.7250	0.3549	2.0802
10	100	200	Par	0.3511	4.2815	0.5121	1.9860
11	50	500	Par	0.0658	0.7088	0.3132	1.4091
12	100	500	Par	0.4283	4.2474	0.3698	1.9344
13	50	200	Per	0.1676	1.3173	0.2013	0.9631
14	100	200	Per	0.6284	3.8996	0.4462	3.2392
15	50	500	Per	0.1370	1.0670	0.0796	0.4902
16	100	500	Per	0.3112	4.1647	0.1221	1.1243
Milling				0.8379	5.2101	1.6741	6.7833

Table 2.—Results of roughness measurements in convex steel workpieces.

Exp. number	*r* (mm)	*a* (mm/min)	*D*	*Ra* // (μm)	*Rt* // (μm)	*Ra* ⊥ (μm)	*Rt* ⊥ (μm)
1	50	200	Par	0.1589	3.2426	0.5230	2.0223
2	100	200	Par	0.8213	6.3732	0.5319	2.2973
3	50	500	Par	0.2195	3.2720	0.7963	3.5370
4	100	500	Par	0.5536	5.3222	0.8184	3.5319
5	50	200	Per	0.1034	0.7153	0.8283	5.4373
6	100	200	Per	0.3355	2.1932	1.3076	7.0976
7	50	500	Per	0.1116	0.7104	0.4285	2.4230
8	100	500	Per	0.1803	1.4868	0.5155	2.1726
9	50	200	Par	0.1631	3.4265	0.6241	2.3306
10	100	200	Par	0.6161	4.5065	0.8296	3.3200
11	50	500	Par	0.3274	6.4135	0.5770	2.5576
12	100	500	Par	0.7527	5.2415	0.6645	2.8229
13	50	200	Per	0.0914	0.5542	0.5985	2.5478
14	100	200	Per	0.1620	1.1320	0.9259	5.1955
15	50	500	Per	0.0887	0.5610	0.4047	2.3786
16	100	500	Per	0.1883	1.1186	0.5030	2.6436
Milling				0.7132	4.8651	1.6760	7.6036

Table 3.—Results of roughness measurements in concave aluminium workpieces.

Exp. number	*r* (mm)	*a* (mm/min)	*D*	*Ra* // (μm)	*Rt* // (μm)	*Ra* ⊥ (μm)	*Rt* ⊥ (μm)
1	50	200	Par	0.1506	1.0582	0.1827	1.0502
2	100	200	Par	0.0964	1.2843	0.1483	0.7812
3	50	500	Par	0.1243	0.6205	0.1570	0.9910
4	100	500	Par	0.0847	0.8121	0.2090	1.1357
5	50	200	Per	0.2217	1.4248	0.1326	1.4239
6	100	200	Per	0.2179	1.3444	0.0594	0.8050
7	50	500	Per	0.1918	1.2466	0.0431	0.3916
8	100	500	Per	0.1307	1.2764	0.0527	0.9787
9	50	200	Par	0.1731	1.5564	0.1290	1.0432
10	100	200	Par	0.0906	0.9665	0.1327	0.9322
11	50	500	Par	0.1151	0.5554	0.1300	1.0337
12	100	500	Par	0.0953	0.8047	0.1554	1.1627
13	50	200	Per	0.2564	1.6647	0.1540	0.8191
14	100	200	Per	0.1743	1.3073	0.0658	0.5035
15	50	500	Per	0.1306	0.8300	0.0744	0.4634
16	100	500	Per	0.1566	1.2015	0.0503	0.9324
Milling				0.2557	1.8200	0.8215	3.6271

Result Analysis of Surface Roughness Measurements

In the result tables (Tables 1 to 4), we can see that the value of the surface roughness decreases compared to the surface roughness of the prior milling operation in case of convex aluminium workpieces. *Ra* decreases by 59% in the parallel measurements to the milling feed-rate and 63% in perpendicular measurements. *Rt* decreases by 52% and 62% in the parallel and perpendicular measurements,

TABLE 4.—Results of roughness measurements in concave steel workpieces.

Exp. number	*r* (mm)	*a* (mm/min)	*D*	*Ra* // (μm)	*Rt* // (μm)	*Ra* ⊥ (μm)	*Rt* ⊥ (μm)
1	50	200	Par	0.1388	1.0509	0.3179	1.4426
2	100	200	Par	0.0979	1.0745	0.1530	0.9431
3	50	500	Par	0.0548	0.3958	0.3552	1.5525
4	100	500	Par	0.0851	0.7004	0.1680	1.0024
5	50	200	Per	0.0855	1.0533	0.3253	2.5111
6	100	200	Per	0.1856	1.7346	0.2663	2.1591
7	50	500	Per	0.0509	0.4388	0.2317	1.9140
8	100	500	Per	0.1327	1.0554	0.2370	2.2532
9	50	200	Par	0.1375	1.0382	0.2996	1.4572
10	100	200	Par	0.1063	1.0487	0.1695	0.6175
11	50	500	Par	0.0669	0.3769	0.3674	1.2996
12	100	500	Par	0.0869	0.9649	0.1504	0.9272
13	50	200	Per	0.0912	1.1307	0.3412	2.8130
14	100	200	Per	0.1504	1.6431	0.2853	2.0080
15	50	500	Per	0.0595	0.4623	0.2389	1.8170
16	100	500	Per	0.3451	1.7514	0.3223	2.5052
Milling				0.4281	3.0103	0.9316	4.5837

TABLE 5.—Obtained coefficients for the regression curves of each index of surface roughness in each experiment.

Term	*Ra* //	*Rt* //	*Ra* ⊥	*Rt* ⊥
Aluminium A92017 convex piece				
Constant	−0.0953	−1.0484	0.076058	1.01988
C1	0.0042	0.0433	0.00773733	0.0289278
C2	0	0	0.00032283	−0.00018392
C3	0	0	−0.446375	−2.25440
C4	0	0	$-1.55467 * 10^{-5}$	$-4.87967 * 10^{-5}$
C5	0	0	0.00833433	0.0418605
C6	0	0	0.000489	0.00296975
C7	0	0	$-1.45767 * 10^{-5}$	$-7.511 * 10^{-5}$
R-Sq adj (%)	70.49	80.63	39.57	73.74
Steel G10380 convex piece				
Constant	−0.135225	1.30213	0.646113	3.36647
C1	0.0058645	0.0211962	0.00329	0.0146180
C2	0	0	$-6.0875 * 10^{-4}$	−0.00340883
C3	0.11625	−1.51433	0.323646	2.38347
C4	0	0	0	0
C5	−0.0035095	−0.00424775	0	0
C6	0	0	$-8.98417 * 10^{-4}$	−0.00547483
C7	0	0	0	0
R-Sq adj (%)	88.39	82.07	55.04	54.5
Aluminium A92017 concave piece				
Constant	0.261406	1.59744	0.2724	2.09622
C1	$-7.9275 * 10^{-4}$	0	−0.0018105	−0.0153868
C2	$-1.46625 * 10^{-4}$	−0.00135808	$-3.74 * 10^{-4}$	−0.0034175
C3	0.0343688	0.035642	0.0399583	0.618725
C4	0	0	$4.25 * 10^{-6}$	$4.40717 * 10^{-5}$
C5	0	0	$-5.565 * 10^{-4}$	−0.00722883
C6	0	0.000369167	$-1.04167 * 10^{-4}$	−0.0022135
C7	0	0	0	$2.22817 * 10^{-5}$
R-Sq adj (%)	77.21	63.93	82.84	58.76
Steel G10380 concave piece				
Constant	0.022525	0.769198	0.400325	3.38701
C1	0.00126225	0.0100652	−0.0018135	−0.0211513
C2	0	−0.00151171	0	−0.00353492
C3	−0.082425	−0.243675	−0.1095	1.11271
C4	0	0	0	$4.33517 * 10^{-5}$
C5	0.00137125	0.00543175	0.0016825	−0.00498133
C6	0	0	0	−0.00276092
C7	0	0	0	$2.94617 * 10^{-5}$
R-Sq adj (%)	42.13	79.95	74.44	94.65

respectively. In steel convex workpieces *Ra* improves by 88% in parallel measurements and by 49% in perpendicular measurements. *Rt* improves by 89% and by 40% in parallel and perpendicular measurements, respectively. For aluminium concave workpieces *Ra* decreases by 77% in parallel measurements and by 74% in perpendicular measurements. *Rt* by 76% and by 60% in parallel and perpendicular measurements respectively. Finally, for steel concave workpieces *Ra* decreases by 90% in parallel measurements and by 89% in perpendicular measurements. *Rt* decreases by 86% in both measurements.

For each evaluated workpiece a regression equation can be obtained in form (1). Each equation allows to determine the value of the surface roughness index (*Ra* //, *Rt* //, *Ra* ⊥, and *Rt* ⊥). With the MINITAB experimental design software, the coefficients of each regression Eq. (1) can be obtained.

First, these regression equations are usually obtained from a general perspective to analyze the significance degree of each evaluated parameter to the measured roughness index. After the experiment is analyzed again by just taking into account the significant parameters. A second curve is obtained fitted to each particular case. Hence, the coefficients for each regression equation vary in a second analysis. The coefficients for each regression equation in each case are shown in Table 5, as well as the adjusted R-squared parameter (R-Sq adj), which indicates the validity level of each experiment:

$$R(aot) = \text{Constant} + C1r + C2a + C3D + C4ra + C5rD + C6aD + C7raD. \quad (1)$$

The result analysis is based upon a Pareto chart as shown in Figs. 3 and 4. We can observe the significant parameters for the result measurements. The measurements were performed according to a 95% confidence level.

Comments on Experimental Results

In a convex surface with a radius between 50 and 100 mm of aluminium A92017, the burnishing process helps to improve the surface roughness of the workpieces tested. The surface curvature radius is the parameter that most strongly determines the final surface roughness. However, in the perpendicular direction to the previous milling feed rate, if the roughness is measured, the tool feed rate is the most significant parameter. This means that the feed rate is very important for flat surfaces, but in curved surfaces the curvature radius definitely determines the surface quality. We have to keep in mind that this happens when we use a constant burnishing force. If the force is not constant, the results can be certainly different.

If a surface of 100 mm radius needs to be burnished, it is highly recommended to do so before a perpendicular milling process. It means drawing straight lines with the burnishing tool, and thus the process develops as if on a flat surface. It is better to burnish a flat surface than a curved surface. In Fig. 5, to summarize, we can see the influence of the experimental parameter values on the index of measured surface roughness.

In a convex surface with a radius between 50 and 100 mm of steel G10380, the burnishing process also helps to improve the surface roughness of the workpieces tested. The burnishing direction is the most significant parameter for this material. Unlike aluminium, the feed rate is not significant in the parallel direction to the feed rate of the prior milling, but it affects the measurements in the parallel direction.

The best roughness values are also obtained on the surface of smaller radius and in case of higher feed rates. In the case of the direction of burnishing, the measurements in the parallel direction to the milling feed rates are smaller for the perpendicular burnishing and in the perpendicular direction to the milling process. The lower roughness values were obtained in the burnishing parallel to the milling feed rates.

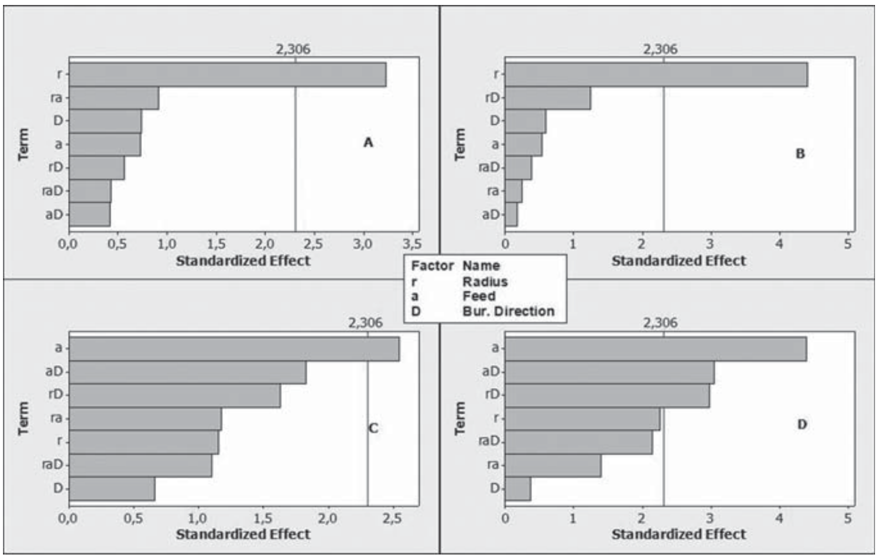

FIGURE 3.—Pareto chart for standardized effects on aluminium A-92017 convex workpieces: (A) *Ra* //, (B) *Rt* //, (C) *Ra* ⊥, and (D) *Rt* ⊥.

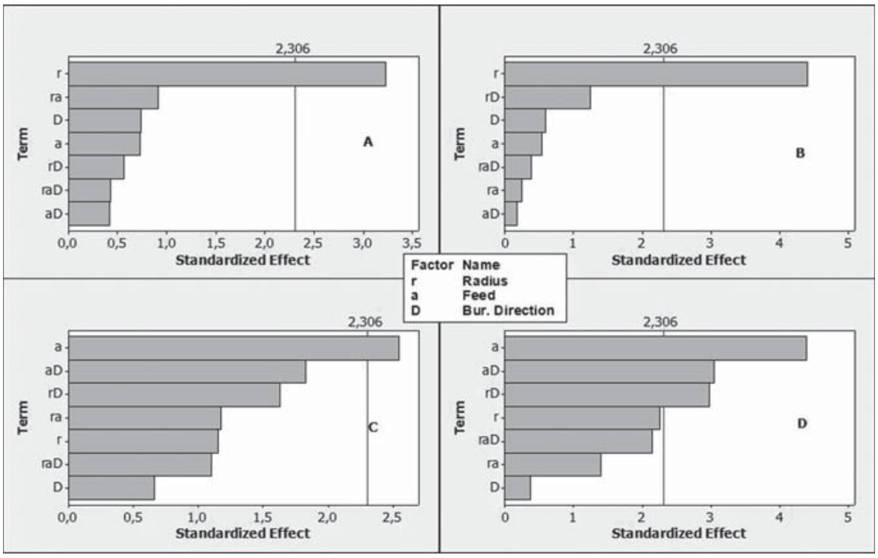

FIGURE 4.—Pareto chart for standardized effects on steel G-10380 convex workpieces: (A) *Ra* //, (B) *Rt* //, (C) *Ra* ⊥, and (D) *Rt* ⊥.

In the summary graph of Fig. 6, previous comments are shown.

In a concave surface with a radius between 50 and 100 mm of aluminium A92017, the ball burnishing process is also suitable for improving surface roughness of the workpieces tested. The direction in which the ball burnishing process has been performed is the parameter that generally affects more the index results of surface roughness in this experiment. The curvature radius also influences this index, obtaining better results with a radius of 100 mm. This is the opposite to what happened in the case of convex workpieces (Fig. 5), where the best results were obtained in surfaces with a radius of 50 mm.

The feed rates also play a role in this case, which has also happened previously in experiments with workpieces of the same material. In the summary graph of Fig. 7, previous comments are shown.

Finally, for a concave surface with a radius between 50 and 100 mm, of steel G10380, successful results were also obtained. The burnishing direction and the curvature radius are the most significant parameters in this experiment. These results are quite similar to those obtained with convex workpieces of the same material. The feed rate is not significant for this material.

The best values of roughness were obtained with a radius of 50 mm in the parallel direction to the milling feed rate

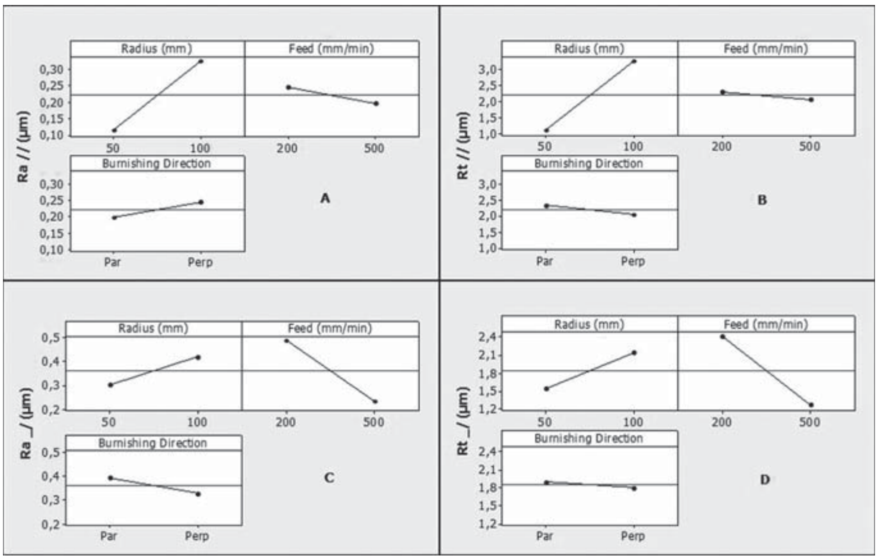

FIGURE 5.—Summary graph of the influence of experimental parameters on the index of measured surface roughness in convex aluminium A92017 workpieces: (A) *Ra* //, (B) *Rt* //, (C) *Ra* ⊥, and (D) *Rt* ⊥.

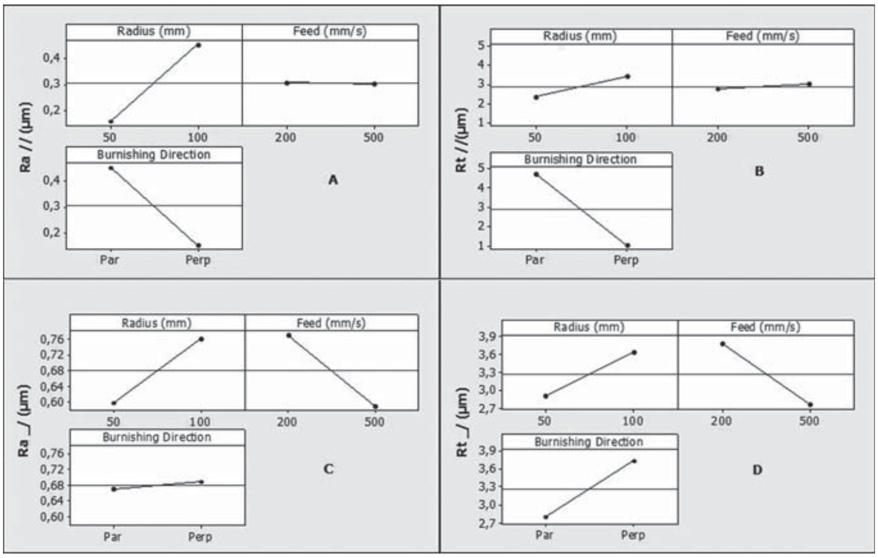

FIGURE 6.—Summary graph of the influence of experimental parameters on the index of measured surface roughness in convex steel G10380 workpieces: (A) *Ra //*, (B) *Rt //*, (C) *Ra* ⊥, and (D) *Rt* ⊥.

and with a radius of 100 mm, in the perpendicular direction to the milling feed rate. In Fig. 8, the previous comments are shown.

Regarding experiments with concave workpieces of aluminium A92017, there are two differences. The first difference is the influence of feed rate on aluminium as discussed above. The second one is that the burnishing direction in the Ra and Rt measurements made in the perpendicular direction to the milling feed rate has an opposite effect compared to an experiment with steel.

On the other hand, if we compare these results with those obtained for convex workpieces of steel G10380, the difference is that the best results for *Ra* and *Rt* measured in the parallel direction to the feed rate on the convex surfaces are more suitable for burnishing done in the perpendicular direction to the feed rate. On the concave surfaces, the best results are more suitable for burnishing performed in the parallel direction to the feed rate. In the case of concave surfaces, the best results in *Ra* and *Rt* measurements in the perpendicular direction to milling feed rate are for surfaces with a radius of 100 mm and in the convex workpieces for surfaces with a radius of 50 mm. The last difference was also found between the concave and convex workpieces of aluminium A92017.

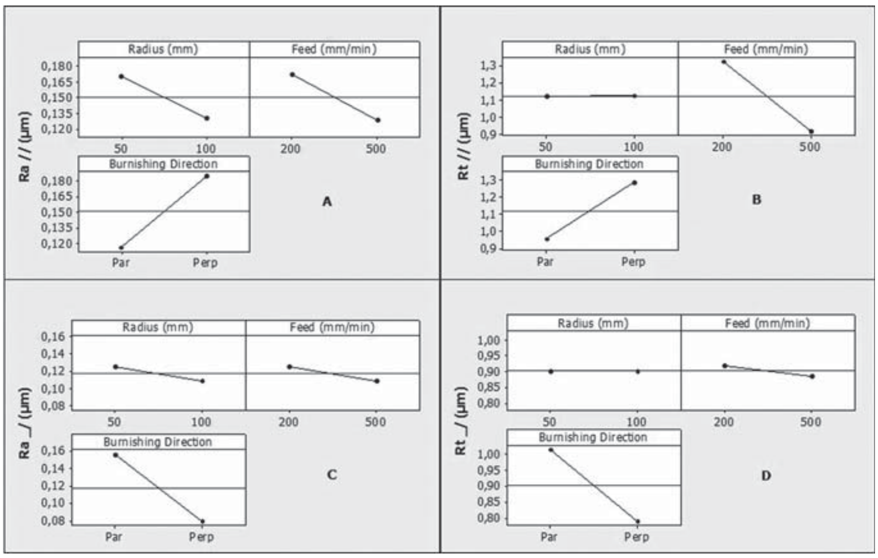

FIGURE 7.—Summary graph of the influence of experimental parameters on the index of measured surface roughness in concave aluminium A92017 workpieces: (A) *Ra //*, (B) *Rt //*, (C) *Ra* ⊥, and (D) *Rt* ⊥.

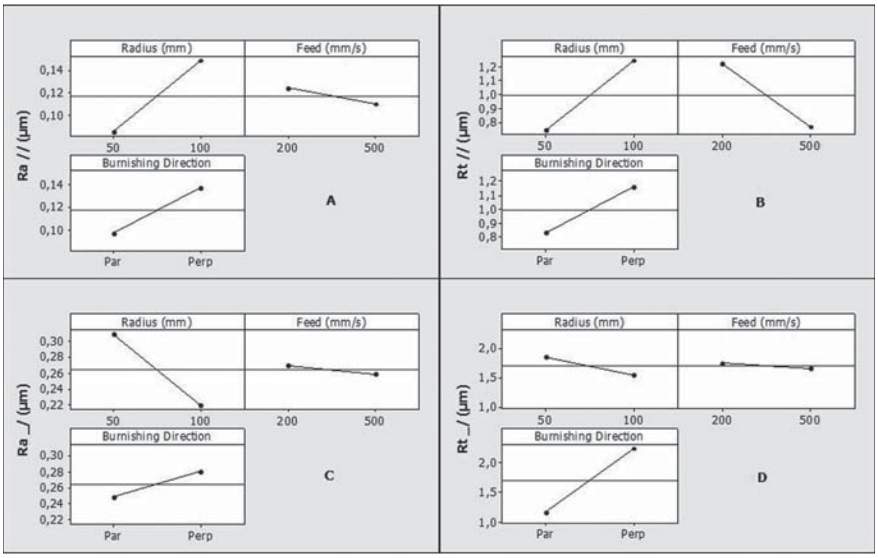

FIGURE 8.—Summary graph of the influence of experimental parameters on the index of measured surface roughness in concave steel G10380 workpieces: (A) *Ra* //, (B) *Rt* //, (C) *Ra* ⊥, and (D) *Rt* ⊥.

TABLE 6.—Recommendations on burnishing process parameters to be used with convex workpieces.

Parameter	Material Indicator	A92017 IL	A92017 Optimal value	AISI 1038 IL	AISI 1038 Optimal value
Feed	*Ra* //	NS		NS	
	Rt //				
	Ra per	HS	500 mm/s	HS	500 mm/s
	Rt per			IS	
Surface radius	*Ra* //	HS	50 mm	HS	50 mm
	Rt //			S	
	Ra per	IS		IS	
	Rt per				
Burnishing direction	*Ra* //	NS		HS	Perpendicular to milling
	Rt //				
	Ra per	IS	Perpendicular to milling	NS	
	Rt per			S	Parallel to milling

IL = Importance level;
HS = High significant;
S = Significant;
IS = Not very significant or significant in combination with another parameter;
NS = Nonsignificant.

TABLE 7.—Recommendations on burnishing process parameters to be used with concave workpieces.

Parameter	Material Indicator	A92017 IL	A92017 Optimal value	AISI 1038 IL	AISI 1038 Optimal value
Feed	*Ra* //	S	500 mm/s	NS	
	Rt //	HS		S	500 mm/s
	Ra per	IS		NS	
	Rt per				
Surface radius	*Ra* //	S	100 mm	S	50 mm
	Rt //	NS		HS	
	Ra per	IS	100 mm		100 mm
	Rt per	NS		S	
Burnishing direction	*Ra* //	HS	Perpendicular to milling	IS	Parallel to milling
	Rt //		Parallel to milling	S	
	Ra per		Perpendicular to milling	IS	
	Rt per	S		HS	

IL = Importance level
HS = High significant;
S = Significant;
IS = Not very significant or significant in combination with another parameter;
NS = Nonsignificant.

Recommendations on Parameter Values

Experiments performed allow us to draw interesting conclusions about the development of future research papers on ball burnishing with concave and convex surfaces using tested materials. These recommendations are summarized in Tables 6 and 7.

CONCLUSIONS

Once this article was finished, we could verify that the ball burnishing process is effective to improve the surface finish of workpieces of different materials and geometric configurations with a certain level of complexity.

The following conclusions can be drawn:

1. The ball burnishing process can be used to improve the finish of complex surfaces.
2. For aluminium A92017, workpieces with concave and convex surfaces have been used. The main parameter value that affects the surface roughness is the curvature radius, achieving better results with a smaller radius in convex surfaces and with a bigger radius in concave surfaces. The direction of the burnishing process related to the milling feed rate is also relevant in curved surfaces.

3. In steel 1038 workpieces with convex or concave surfaces were evaluated as well. The prior peak height produced by the milling process is the parameter value that affects more the indexes of surface roughness. The feed rate has no influence whatsoever, because this material has a high coefficient of self-hardening. The burnishing direction and the curvature radius are also significant parameters.

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