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BALL-BURNISHING PROCESS INFLUENCE ON HARDNESS AND RESIDUAL STRESSES OF ALUMINIUM A92017

José Antonio Travieso-Rodríguez, Hernán González-Rojas, Giovanni Gómez-Gras
Escola Universitària d’Enginyeria Tècnica Industrial de Barcelona. Universitat Politècnica de Catalunya. Mechanical Engineering Department.
C/ Comte d’Urgell, 187, Barcelona, Spain

Gilles Dessein, Joël Alexis
École National d’Ingénieurs de Tarbes.
47, avenue d'Azereix. BP 1629 - 65016 Tarbes CEDEX
France

ABSTRACT

The ball-burnishing process is done firstly, to improve the surface finish of workpieces that have been previously machined and secondly, to obtain a harder surface with a compressive residual stress map. In this way we will obtain a surface that is more resistant to wear and fatigue. In this paper we present results of tests performed with this process that was applied to workpieces with a convex surface of aluminium A92017. An experiment to do tests was designed. Measurement results of surface hardness and residual stress are presented in this paper as well. These results are compared to those measured in the workpieces before being burnished. Finally conclusions are drawn about the improvement of these properties applied to workpieces through the ball burnishing process. The main innovation of this paper is that we work on convex geometries. We also obtain a table of recommended parameter values for the process.

Keywords: Burnishing, Manufacturing, Hardness, Stresses, Surface

1. INTRODUCTION

A good surface property on a complex surface geometry is a very difficult problem to be solved. When the development surface is complex, improving its quality is not that simple. Through a ball-burnishing operation surfaces of complex configuration could be machined to obtain a good surface finish on them. The ball-burnishing process does not only improve the surface quality, but also firstly it increases the surface hardness, which may be convenient for some practical uses. Secondly it changes the residual stress map that remains on surface layers of the workpiece. As shown in figure 1, the ball-burnishing 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. The workpiece surface is also hardened and it is exposed to compressive residual stresses.

A ball-burnishing process is recommended because the tool can be easily installed on the same CNC machine. The ball operates under the action of a normal force high enough to deform peaks of the surface profile to be treated. The ball is in contact with the surface just for burnishing it. As it happens in the cutting process, plastic deformation is produced on the entire surface because the workpiece is compressed by the application of a ball or roller to produce a smooth and work-hardened of surface irregularities according to El-Tayeb *et al* [1].

The ball-burnishing is considered by Srinivasa *et al*, [2] as a cold working process, which can be used to improve surface characteristics. According to these authors, most papers which have been published before refer to effects of the 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 was performed. They finally drew the conclusion that the ball-burnishing process improves the surface finish and hardness of non-ferrous metals up to a certain extent. According to Srinivasa *et al*, [3]; Hamadache *et al*, [4], and Celaya *et al*, [5]; burnishing is used increasingly as a finishing operation which gives additional advantages such as increased hardness, fatigue strength, and wear resistance. Experimental work based on 3^4 factorial design was carried out to establish the effects of ball burnishing parameters on the surface hardness of low alloy steels specimens.

Most of the research papers, as it can be seen, focused on experimental tests in flat or revolution workpieces. The main purpose of this paper is to analyze how process parameters influence on the micro-hardness and the residual stresses map of burnished convex surfaces of aluminium A92017 and also to make recommendations about their optimal values to be used in this process. The main innovation is that we work on convex geometries. The results of this work are very important to the industry. They can be taken as guidelines for machining the surface type studied, which is present in many mechanical components such as dies and molds.

To perform this study a 3^2experiment will be developed. System parameters will vary between three values. The variation impact on the results of measured micro-hardness and residual tensions is obtained, as well as their best values.

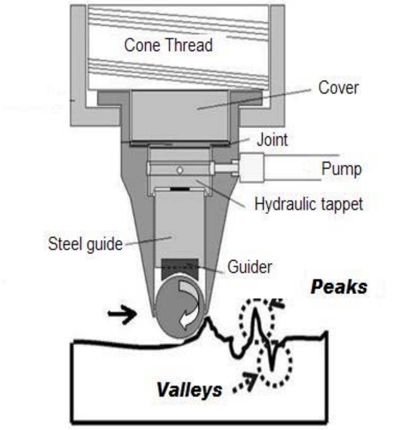

Figure1. Schematic representation of the Ball Burnishing process

Figure 2. Workpiece of aluminium A92017 used in experiments

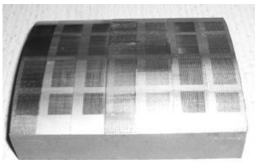

Table 1. Results of micro-hardness test

Exp. Number	*r (mm)*	*a (mm/min)*	*D*	Micro-hardness *HV*
1	50	200	//	125,5
2	100	200	//	178,5
3	50	350	//	127,3
4	100	350	//	138,5
5	50	200	⊥	136,6
6	100	200	⊥	186,3
7	50	350	⊥	130,0
8	100	350	⊥	141,6
Milling				119,9

2. EXPERIMENTS

2.1. Study on the micro-hardness in convex workpieces of aluminium A92017

To verify if the burnishing process increases the hardness on wavy surfaces, a workpiece with three convex surfaces with radii of curvature of 50mm, 100mm and 50mm each was used, like the one represented in Figure 2. On this workpiece 8 different surfaces were burnished and then their micro-hardness was measured on HV scale. On each surface process parameters differ. The micro-hardness in milled areas was measured as well. Parameters used as burnishing process variables were as follows: the radius of curvature of the burnishing surface r, the feed-rate of the burnishing tool a, as well as the machining strategy involving the burnishing direction D which was performed parallel to the milling feed direction (//) or perpendicular to it (⊥). These particular variables were applied since in previous experiments (Travieso *et al*, [6]) it was proved that they have a large influence on surface characteristics of workpieces. Parameters combined at two different levels each had 8 experiments as a result. In this way, to what extent the surface hardness of burnished workpieces varied compared to the milled ones could be determined. And how the variability of process parameters affected final results of surface hardness could also be analyzed.

The surface micro-hardness test was measured in HV scale, with an upload of 10N. Measurement results can be seen in table 1.

As shown in Table 1 for results and regardless of parameter values, the value of the surface micro-hardness increased in relation to the one that had remained on the surface as a product of the previous milling operation, 17% on average. Results were analyzed with the Minitab software. The only statistically relevant parameter that had some influence on results was the radius of surface curvature, with R-Sq(adj)=71.33%.Pareto's diagram proving previous results is shown in Figure 3. In this graph the only relevant variable is the radius of surface curvature r whose standardized effect exceeds the 26.88 limit. As shown the radial effect was higher than the one of feed-rate. This was likely due to the fact that the burnishing force component applied all along the surface changed its value because of the surface inclination. Although feed rate was not a significant parameter, it had some relevance for the analysis, as it is shown in Pareto's diagram. The reason is that strain hardening depends on strain feed-rate which also depends on burnishing feed-rate. In this case the value of surface micro-hardness could be estimated with assessed parameters by means of the expression (1).

$$HV = 98.4750 + 0.6275\, r \qquad \ldots(1)$$

Then the confidence interval was estimated for the constant in equation (1) as well as a significance test for the correlation between radius of curvature and micro-hardness. The significance test for correlation drew as a result that F for Fischer F1=6.218 and F2=5.98738. If F1>F2, it meant that there was a correlation between data obtained in the experiment. So it proved that there was a correlation between the workpiece radius of curvature and micro-hardness results obtained. The confidence interval for the constant in equation (1) equals ±48.6796 and ±0.6158 respectively. Analysis results can be seen in figure 4.

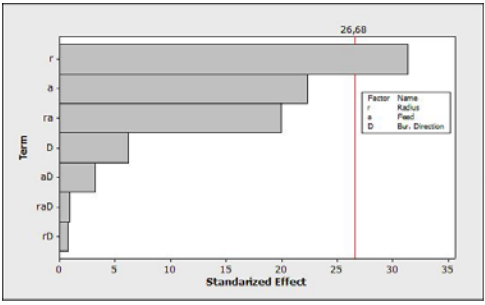

Figure 3. Pareto's diagram for standardized effect of HV

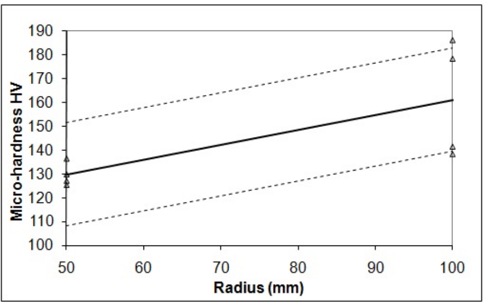

Figure 4. Linear regression showing the influence of the curvature radius variation on HV

As it is known, the radius was the only significant parameter. As the radius increased, micro-hardness values increased since the force component applied to the surface in a large radius was higher than the one applied in a smaller radius. Therefore, the tool exerted more force on workpiece surfaces of radius 100mm than on surfaces of radius 50mm.

2.1.1. Recommendations on parameter values

According to results, obtained parameter values of the system for each case can be recommended to obtain best results. They are: **feed 200mm/min; curvature radius: 100mm and burnishing direction perpendicular to milling.**

2.2. Study on residual stresses on convex surfaces of aluminium A92017

To verify what happened on the inner layers of the burnished workpiece material, remaining residual stresses were measured after the process. Two samples of the convex workpiece of aluminium A92017 were used. Sample surfaces have radii of curvature of 100mm and 50mm each.

To measure residual stresses the diffraction of X-rays technique was applied. This technique allows measuring the strain of the crystal lattice, whereas the stress is determined from the spring constants for diffraction of X-rays. According to Bragg's Law (2) directions in which the diffraction of X-rays on a crystal surface generates interferences can be studied, since it allows anticipating the angles in which X-rays are diffracted by a material with an atomic structure of crystal.

$$m\lambda = 2d\sin(\alpha) \qquad \ldots(2)$$

Where: λ- Wavelength of X-rays; m- Order; d- Spacing between planes of the crystal lattice; α- Angle between incident rays and scatter planes

For each material the diffraction peak corresponding to the diffraction angle which provided more intensity and resolution was determined. This peak could be measured for angles of inclination of different crystals φ, in relation to the workpiece surface. This also meant that there was a diffraction peak associated to each diffraction plane to be measured.

For workpieces of aluminium A92017, the angle of inclination with the highest intensity peak was 2α=112º. In graph of Figure 5, ranges of diffraction peaks for this particular angle in case of workpieces with 100 can be seen. The range of diffraction peaks was associated to the stress condition in material planes. Values were applied to a wavelength of radiation λ=0.1541874nm

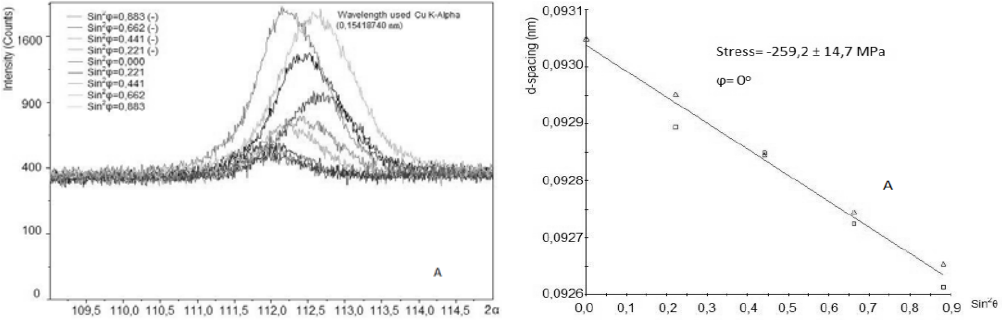

Figure 5. Angle variation for different intensities of radiation and Spacing variation between planes d, as a function of the Θ angle sinus and value of residual stresses obtained, for workpiece with 100mm curvature

According to Bragg's Law spacing between planes of crystal lattices were measured and spacing between diffraction planes d was related to the sinus angle of inclination in different crystals φ (figure %). Triangle-shaped dots represent values for positive φ angles, whereas square-shaped dots stand for negative angles. The solid line represents the estimated tendency for such values. For value φ=0º, the value of residual stresses was determined via the center of gravity method. This calculation was possible due to the fact that stresses were proportional to strains in the equation format (3).

$$\sigma = E{\cdot}\varepsilon \qquad \ldots(3)$$

Where: σ- Residual stress; E- Young's Module; ε- Strain measurement

Values obtained were -259.2MPa and -130.9MPa. The minus sign means that stresses were compressive. This performance is related to both workpieces despite their radii of curvature.

3. CONCLUSIONS

The ball-burnishing process increases micro-hardness values by approx. 17% on convex surfaces of aluminium A92017. The process also provides residual stresses of compressive type, which are likely to increase the fatigue service life of workpieces. Each assessed process parameter has a specific value with which the best micro-hardness results are obtained.

4. REFERENCES

[1] EL-TAYEB, N.S.M.; LOW, K.O.; BREVERN, P.V. Enhancement of surface quality and tribological properties using ball burnishing process. Machining Science and Technology, 12-2, 2008, 234-248.

[2] SRINIVASA, D.; SURESH-HEBBAR, H.; KOMARAIAH, M.; KEMPAIAH, U.N. Investigations on the Effect of Ball Burnishing Parameters on Surface Hardness and Wear Resistance of HSLA Dual-Phase Steels. Materials and Manufacturing Processes, 23-3, 2008, 295-302.

[3] SRINIVASA, D.; SURESH-HEBBAR, H.; KOMARAIAH, M. Surface hardening of high-strength low alloy steels dual-phase steels by ball-burnishing using factorial design. Materials and Manufacturing Processes, 22-7&8, 2007, 825-829.

[4] HAMADACHE, H., LAOUAR, L., ZEGHIB, N.E., CHAOUI, K. Characteristics of Rb40 steel superficial layer under ball and roller burnishing. Journal of Materials Processing Technology 2006, 180, 130-136.

[5] CELAYA, A., RODRÍGUEZ, A., ALBIZURI, J., LÓPEZ DE LACALLE, L. N., ALBERDI, R. Modelo de elementos finitos del bruñido. 9º Congreso Iberoamericano de Ingeniería Mecánica, 2009, Spain, 147-154.

[6] TRAVIESO-RODRÍGUEZ, J.A., DESSEIN, G., GONZÁLEZ-ROJAS, H.A. Surface finish improve of concave and convex surfaces using a ball-burnishing process. Materials and Manufacturing Processes, 2011, 26:12, 1494-1502.