Journal of Materials Processing Technology 211 (2011) 84–94

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Surface layer characteristics due to slide diamond burnishing with a cylindrical-ended tool

Mieczyslaw Korzynski[a,*], Janusz Lubas[a], Slawomir Swirad[b], Kazimiera Dudek[b]

[a] Institute of Technology, Faculty of Mathematics and Natural Sciences, Rzeszow University, Aleja Rejtana 16c, 35-959 Rzeszow, Poland
[b] Mechanical Engineering and Aeronautics Faculty, Rzeszow University of Technology, W. Pola 2, 35-959 Rzeszow, Poland

ARTICLE INFO

Article history:
Received 8 April 2010
Received in revised form 25 July 2010
Accepted 28 August 2010

Keywords:
Slide burnishing
Surface texture
Microhardness
Stresses

ABSTRACT

The article presents an unconventional method of finishing shafts – slide burnishing with a cylindrical-ended tool whose axis is perpendicular to that of the worked shaft. The contact area of the tool with the workpiece and the tool force necessary for burnishing 42CrMo4 alloy steel shafts were calculated. The effect of burnishing parameters on the surface stereometric structure, the surface layer hardening and the distribution of final stresses was examined. Compared with grinding, a considerable improvement in surface condition indicators was found and it was possible to achieve a surface roughness, *Sa* of 0.05–0.18 μm. Surface microhardness increased by up to 29% and compressive stresses of up to a 400 MPa of the absolute value occurred in the surface layer. The effect of burnishing parameters on surface roughness, *Sa* and oscillatory bending strength were examined and the relevant mathematical models – multinominals of the second order that also allow for the interaction of input factors were obtained. Fatigue strength improved (compared to that of the ground workpieces) by 18%. It was found that those effects can be achieved without a lot of technological effort.

1. Principle of the process

Slide burnishing is a finishing method whose kinematics are like those of roller pressure burnishing. However, during slide burnishing, the tip of the burnisher does not roll but slides over the treated surface. The surface layer of the treated element is subjected to cold plastic deformation and this confers adequate properties: surface roughness is reduced, compressive stresses are created in the surface layer which becomes harder. Such a condition of the surface layer improves many usable properties, particularly fatigue strength. For example Benedetti et al. (2002) found a clear dependence of fatigue strength on the state of stress in the surface layer. Applying shot peening, which retains austenite and refines its microstructure and, most of all, increases compressive stresses, they improved the fatigue strength of the gears made of 16MnCr5 low carbon steel by 20%. However, Novovic et al. (2004) found clear effects of both surface topography and surface layer stress condition on fatigue strength. A similar, beneficial effect of compressive stress as well as lower surface roughness on fatigue strength was found by Carvalho and Voorwald (2007), who applied glass peening to a 7050-T7451 aluminum alloy.

Slide burnishing is easy to implement and does not require any complicated equipment. This sort of machining is possible provided the tool is made of a material of sufficient hardness, abrasion resistance and has a low metal slide friction coefficient. Only then is cold plastic deformation of a material burnished with tool sliding possible. Diamond has all the properties required to be applied in slide burnishing tools. However, until recently, it was not possible to produce large-scale diamond tools. For that reason slide burnishing has been and still is most often performed with ball-shaped endings made of various diamond composites or monocrystalline diamonds of 1ct content of synthetic or natural diamond. Contemporary materials technology allows for the production of larger and larger diamond composite elements, so now making, e.g. small cylinders from a few millimeters to several dozen millimeters in diameter and length is fairly easy technologically. This makes possible the advancement of machining technology, including the development of the new methods of burnishing such as slide diamond burnishing with cylindrical tools. Such a process was investigated by Luo et al. (2006), who tested the slide burnishing with PCD roller but having the axis parallel to the axis of the burnished shaft. They checked only microhardness changes, found (for Al-alloy LY12 and brass H62) its 20–25% increase after burnishing.

In the present work the process of slide burnishing carried out with a cylinder-shaped tool and its effect on surface layer condition and on fatigue strength has been studied. This process is unique among the standard methods of burnishing. Its principle is shown in Fig. 1. The axis of the tool is perpendicular to and passes by the axis of the machined shaft. Such a shape and location of the tool does not need the burnisher to be positioned precisely in the axis

* Corresponding author. Tel.: +48 17 8721103; fax: +48 17 8721282.
E-mail address: mk@univ.rzeszow.pl (M. Korzynski).

0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2010.08.029

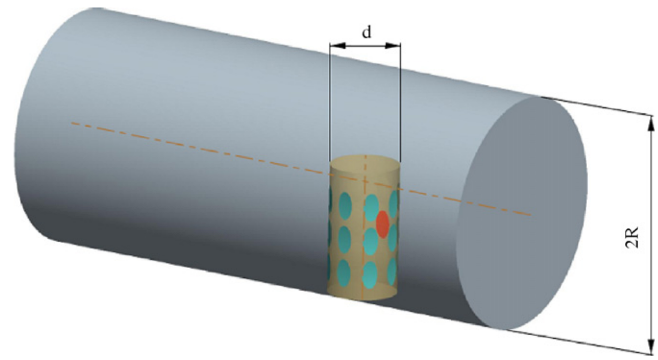

Fig. 1. Slide burnishing with cylindrical element: 1 – object burnished, 2 – cylindrical burnishing tool of radius r, 3 – tool holder, 4 – pressure control spring, n – rotational speed [rev/min], f – feed [mm/rev], F – burnishing force.

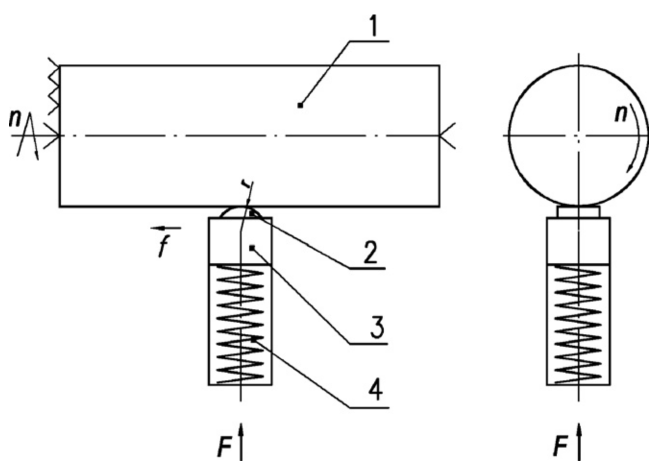

Fig. 2. Possibility of burnisher working surface multiplication: d – diameter of the tool, R – radius of the workpiece.

of the workpiece. As the tool wears out (Fig. 2), it can be moved as appropriate vertically and/or turned relative to its axis in a specially designed tool holder. This enables the working surfaces of the tool to be multiplied and consequently prolonging its lifetime.

2. Tool and burnished workpiece contact surface and burnishing force

The model shown in Fig. 3 was used for the analysis of kinematic dependences in the process of slide burnishing with a cylinder-shaped tool. In the first approximation it was assumed as follows: $l = f/2$, lack of elastic strain, no swell in front of and no flash behind the tool. Based on these assumptions, it follows from the geometric dependences in Fig. 3 that:

$$\left(\frac{f}{2}\right)^2 = r^2 - (r-g)^2 \quad (1)$$

Having solved the above equation one gets a formula which makes it possible to define the extent of the feed

$$f = 2l = \sqrt{8rg - 4g^2} \quad (2)$$

and, after ignoring the lows of higher order, one gets the formula:

$$f = 2l = \sqrt{8rg} \quad (3)$$

from which, for a specific plastic indentation into the treated surface made with a tool of a radius r, it is possible to calculate the length of the contact surface of the tool and the workpiece feedwise.

It is well-known that in order to ensure good burnishing results it is necessary to carry out machining so that each point of the burnished surface should not be deformed too many times. Usually one pass of the tool and appropriately selected feed are applied so that the deformation multiplicity of each point of the burnished surface will be under 10. El-Axir et al. (2008) write that an excessive number of passes leads to an increase in burnished surface average roughness and Yeldose and Ramamoorthy (2008) found that an excessive number of tool passes causes peeling-off. Thus, an appropriate feed level must be applied. A decrease in feed at a constant burnishing depth g will cause a proportionate multiplication factor increase. From the above presented formula it follows that, at a plastic indentation depth within the roughness height of the treated surface (according to the opinion presented by Korzynski (2007) and Shiou and Chuang (2010) it is the optimum plastic interference depth at finishing burnishing), i.e. when r is from 4 to 8 mm and when Sz is 1.5 to 3 μm (typical after-grinding values; grinding is applied before burnishing), the length of the contact track $2l$ is from 0.2 to 0.4 mm. Thus, to obtain an adequate (2–8) multiplication factor, it is necessary to apply a 0.05–0.10 mm/rev feed.

In elastic pressure burnishing, tool interference is controlled by selecting the appropriate pressure force of the tool. It should be chosen in such a way that the stresses in the contact area should be higher than the yield point of the worked material. Thus, the value of the force depends on the size of the contact area being formed due to the interaction of the workpiece and the tool during burnishing (and on the properties of the material that is being treated assuming that the material the tool is made of is undeformable). The contact area that is formed then, due to the interference of two rollers of perpendicular generating lines, has an ellipsoid-like shape. In the first approximation the following assumptions were made to analyze the contact area related issues:

- $g \ll r$,
- $R > r$,
- the angle between the burnisher axis and that of the workpiece is 90°,
- the tool is made of an ideally rigid material (there are no plastic deformations).

For such a model of the process the contact area can be expressed as:

$$A = \Pi BC = 2\Pi g\sqrt{r \cdot R} \quad (4)$$

where R – burnished workpiece (treated shaft) radius.

It is an established fact that during burnishing plastic deformations are responsible for the contact ellipsis being deformed as shown in Fig. 4, which indicates that the actual contact area during burnishing will be smaller than A. If the machined material were perfect plastic (no flash in front of and behind), then, at the same tool interference and its rounding radius, the contact area would be

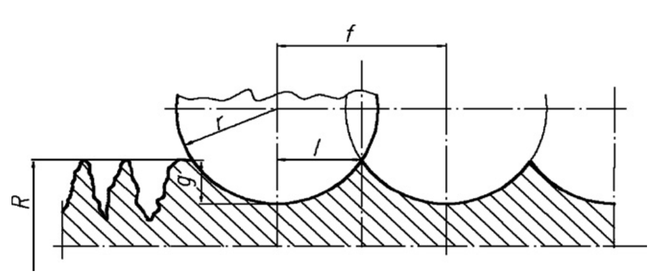

Fig. 3. Model of slide burnishing realized with a cylindrical-shaped tool: r – radius of the tool, f – feed, l – length of the contact zone along the direction of feed, g – value of plastic interference of the tool into the surface burnished (depth of burnishing, plastic indentation depth), R – radius of workpiece (burnished shaft).