Materials Science Forum
ISSN: 1662-9752, Vol. 918, pp 117-122
doi:10.4028/www.scientific.net/MSF.918.117

Submitted: 2017-10-05
Revised: 2017-12-06
Accepted: 2017-12-14
Online: 2018-03-20

Experimental Investigations of Bulge Formation for Burnishing on Plain Surfaces

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Keywords: burnishing, surface integrity, finishing

Abstract. Burnishing as a forming finishing process enables the production of precise and mechanical compressed surfaces. The forming operation can be easily integrated into cutting processes due to its kinematic similarities. Through this integration it was possible to create highly efficient process chains for the machining of rotational symmetrical parts. The formed surface qualities are also interesting for prismatic geometries, but the adaptation of this force controlled process is challenging, because of its multiaxial characteristics.
A main limiting factor for burnishing on plain surfaces is the formation of a burnishing bulge on the edges of the burnished area. Several investigations of the process on plain surfaces where done to analyse the bulge formation characteristics of the aluminium EN AW-2007 material. Experiments of different single burnished paths and burnished areas with the subsequent 3D capturing of the created surfaces were done.
The investigations show, that the deformation is highly dependent on the applied burnishing force and the burnishing feed. The length and width of the burnished area does not have an influence on the bulge formation.

Introduction

Burnishing is a widely established finishing process to increase surface quality, dimensional accuracy and strength of a part [1]. It is a forming process, which utilizes a spherical or cylindrical burnishing tool. Under the applied burnishing force the tool deforms the surface, but does not change the macro geometric shape of the workpiece [2]. As far as surface quality is concerned, burnishing can compete with the grinding process and offers additional benefits, like an increase in vibration and corrosion resistance of the treated part [3-5]. In contrast to the grinding process, burnishing does not need a separate machine and can be used on conventional turning and milling machines without the need of a coolant [6]. The advantages of burnishing make it to a widely adopted process in industries like automotive, hydraulic/pneumatic and manufacturing engineering [7]. Its application enables a reduction of manufacturing costs of up to 50% and an increase in lifetime of a part by a factor of 10 [8].

The burnishing process is currently limited to rotational symmetrical parts mostly manufactured by turning. By aligning multiple burnishing paths next to each other on a plain surface, as shown in Fig. 1, it is possible to adopt this manufacturing process on those plain and even prismatic surfaces. First studies on this topic were already done in 1963 [9]. Those investigations show, that burnishing on milling machines can achieve similar results like on turning machines. This means a reduced surface roughness, an increase in wear resistance, a productivity increase of up to 50% and cost reductions of up to 30%. This process was limited to plain surfaces, but recent investigations on 5-axis-milling machines show, that burnishing on prismatic surfaces is possible [10].

During the burnishing of rotational symmetrical parts a bulge in feed direction is formed [2, 11]. This bulge can increase during the burnishing process and lead to surface damage [12, 13]. Own first investigations show, that this bulge is also formed on plain surfaces. Thus far there are no investigations regarding the relevant process parameters causing the bulge formation on plain surfaces. The bulge formation must be understood and controllable for the best surface finish. The focus of the investigations presented in this paper is to give further insight into the development of this burnishing bulge on plain surfaces.

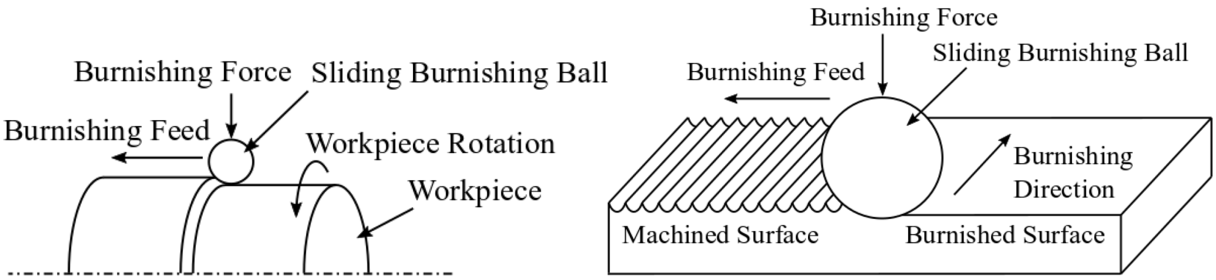

Fig. 1. (left) Conventional burnishing of rotational symmetrical parts, (right) Burnishing on plain surfaces by aligning multiple straight burnishing paths next to each other

Experimental Setup

Setup and specimen preparation. For the investigations an existing machine setup for burnishing on a 3-axis milling machine was used. This experimental setup includes a 6-axis-force-measurement platform, where the specimen were screwed directly onto, as well as an overload protection. The specimen was premachined by milling on the same clamping to ensure a plain surface without introducing additional errors by reclamping. The burnished material was aluminium EN AW-2007 (3.1645). The material properties of this specific aluminium are shown in Table 1.

Table 1. Material properties of the workpiece material aluminium EN AW-2007 (3.1645)

Yield strength	220-250 [MPa]
Ultimate tensile strength	340-370 [MPa]
Young’s modulus	70 [GPa]
Poisson’s ratio	0.33

Burnishing bulge investigations. The main focus was to analyse the forming of the burnishing bulge frontal and lateral of the burnishing tool. A diamond burnishing tool with a tool radius of 5 mm was used. The burnishing force the tool applies onto the surface is set by changing the infeed. Own investigations have shown that the force applied by the burnishing tool has a linear dependency on the infeed between 150 and 400 N, with 400 N being the maximum possible burnishing force the tool can apply. Considering this linear dependency the investigated burnishing force F was chosen to be 200, 275 and 350 N and the infeed was set accordingly.

The investigation of the burnishing bulge was split into two parts. The first part was focused on the frontal bulge. This was done by burnishing a straight single path with different length s of 5, 10 and 20 mm. Those lengths were chosen to be equal to 100%, 50% and 25% of the length of the specimen. The second part was the investigation of the lateral burnishing bulge by burnishing an area. This was achieved by aligning multiple burnishing paths next to each other. The length of this area was 20 mm, which is the length of each individual burnishing path. Different widths b of the burnishing area of 2, 4 and 8 mm were burnished and the burnishing feed f was set to 0.125, 0.25 and 0.5 mm. In all experiments the burnishing velocity v was set to 1 m/min.

Measurement Methodology

The surface of the burnished path was measured with a 3D-laser-scanning-microscope. The investigation of the burnishing bulge was done by extracting the surface profile along the burnishing path for the frontal bulge as seen in Fig. 2 (top left). The lateral bulge was investigated by extracting the surface profile perpendicular to the burnishing path as seen in Fig. 2 (top right). The two surface profiles are similar, which makes it possible to use the same mythology to characterise the bulge. As shown in Fig. 2 (bottom) the bulge depth *d* is the depth of the tool indentation, which is calculated as difference between the unburnished surface (*0*) and the minimum value of the surface profile (*min*). The bulge height *h* characterizes the amount of material piled up by the tool and is calculated as the difference between the maximum value of the surface profile (*max*) and the unburnished surface (*0*). The width of the bulge *w* is the distance between the minimum and maximum values of the surface profile.

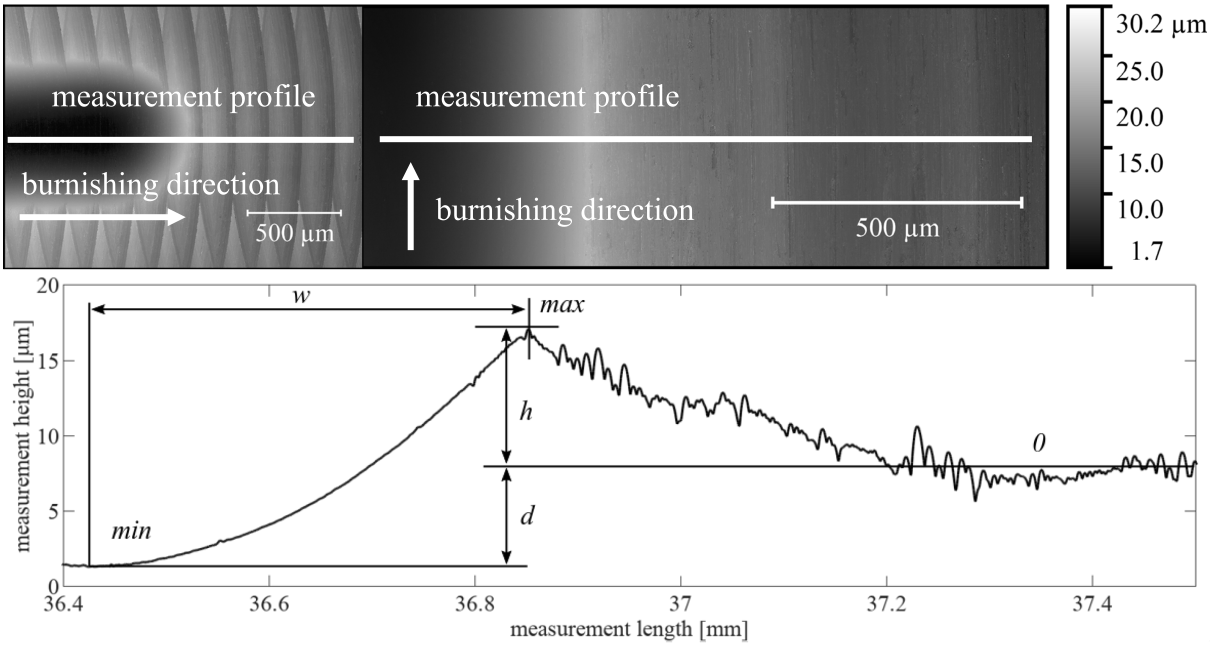

Fig. 2. (top left) Bulge of a single burnishing path, (top right) Bulge of a burnished area, (bottom) Surface profile of the burnishing bulge and measurement points for its characterization

Results

As stated before the frontal and lateral bulge of the burnished path are the main focuses of these investigations. Fig. 3 shows the burnishing force during the burnishing process of the single burnishing path. The peaks for the burnishing force come in three sets with three peaks for each set. Each set has a different and more important constant burnishing force which is in good agreement with the defined burnishing forces of 200, 275 and 350 N. The different times for each peak in a set can be traced back to the different burnishing path length and again are in good agreement with the chosen burnishing velocity and path lengths.

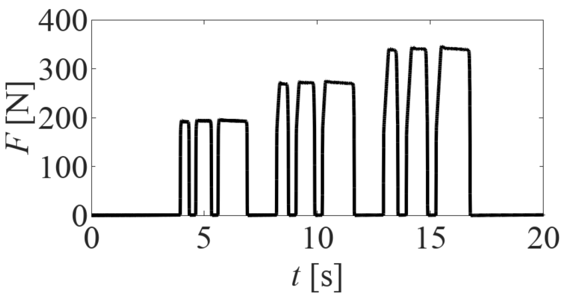

Fig. 3. Burnishing force during burnishing of a single path, 3 sets of peaks for burnishing forces of 200, 275 and 350 N, each set has different burnishing path lengths of 5, 10 and 20 mm shown by different burnishing times

The evaluation of the frontal and lateral burnishing bulge was done by observing the bulge depth *d*, bulge height *h* and bulge width *w*. The dependency of those values on each parameter on can be seen in Fig. 4 and 5. Each value in the Figures is calculated by choosing a process parameter and averaging the measured values for each value of the chosen parameter. This methodology allows for an independent estimation of the influence of the each parameter on the burnishing bulge. Additionally the Pearson correlation coefficient *p* was calculated for each parameter and measurement-value combination. This coefficient indicates the degree of linear correlation between two values and can be any number between -1 and +1. In this context +/-1 means a positive/ negative correlation and 0 means no correlation.

Frontal bulge. The frontal bulge is important for a reliable and stable process. Should the amount of material in front of the burnishing tool increases during the process, the burnishing force can rise due to the constant infeed. An undefined increase in burnishing force can in turn lead to tool damage and an increase in surface stress. This can cause material failure and cracks and therefore bad surface quality. These concerns are unfounded because of the constant burnishing force as seen in Fig. 3 and stated above.

As seen in Fig. 4 the burnishing force F has a strong influence on the burnishing bulge depth d, height h and width w. With p over 0.9 for all three measurement values it can be assumed, that there is a true correlation between F and d, h and w. With increasing burnishing force F the three values increase as well. On the other hand the burnishing path length l has no influence on the burnishing bulge depth d, height h and width w, as show in the graphs. This claim is also underlined by p being less than 0.2 for all three values.

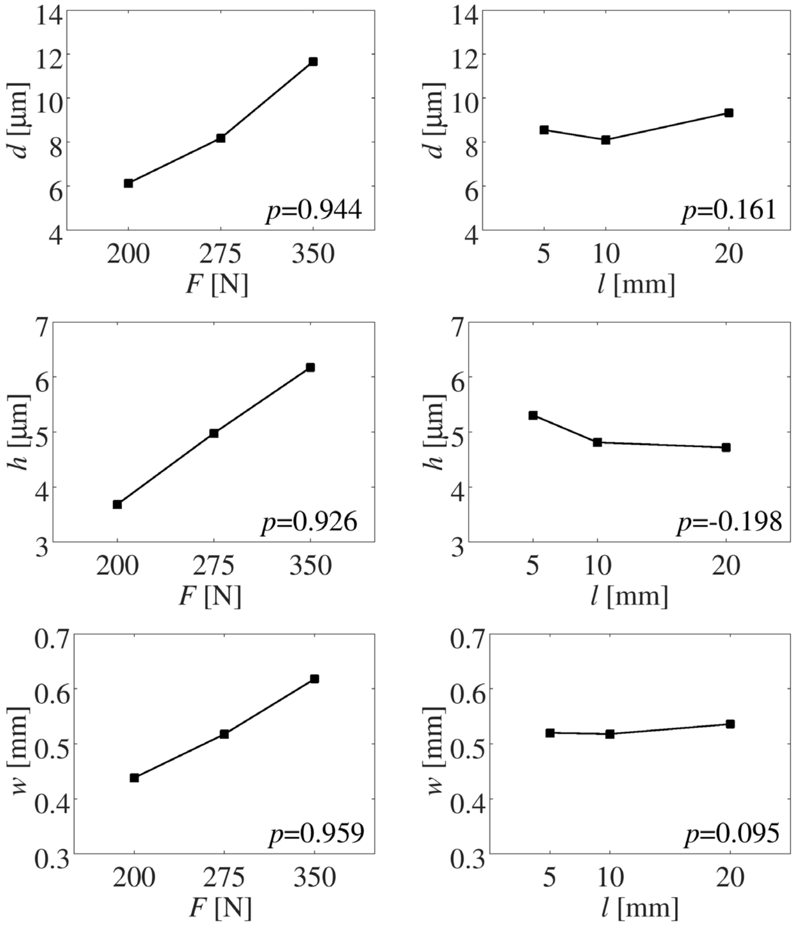

Fig. 4. Bulge depth d, height h and width w in relation to the burnishing force F and the burnishing length l for the frontal burnishing bulge

Lateral bulge. The lateral bulge forms the final burnishing roughness and waviness of the surface. A characterization is therefore important to achieve a high surface quality with the burnishing process. As Fig. 5 shows, the burnishing force F has an influence on bulge depth d, height h and width w. In contrast to the frontal bulge p only lies between 0.6 and 0.8, which means a linear dependency between F and h, d and w cannot be safely assumed. Higher burnishing forces F increase the three measurement values, but a dependency might be of second or third order. The width of burnishing area b has no influence on bulge depth d, height h and width w, which is also proven by p of less than 0.1. The burnishing feed f too has no clear influence on bulge depth d, with p of only 0.343. On the other hand the burnishing feed f may have an influence on bulge height h and width w. Although a higher burnishing feed f decreases the two values by the same amount as higher burnishing forces increase them, a p of -0.72 for the h-f- and -0.493 for the w-f-correlation do not state a clear linear dependency. A possible explanation is a dependency of second or third order, or an interaction of the burnishing feed *f* with one of the other two parameters. The burnishing force *F* is the obvious candidate for an interaction, because it also shows a high influence on the bulge shape, but *p* is not high enough to assume a linear dependency.

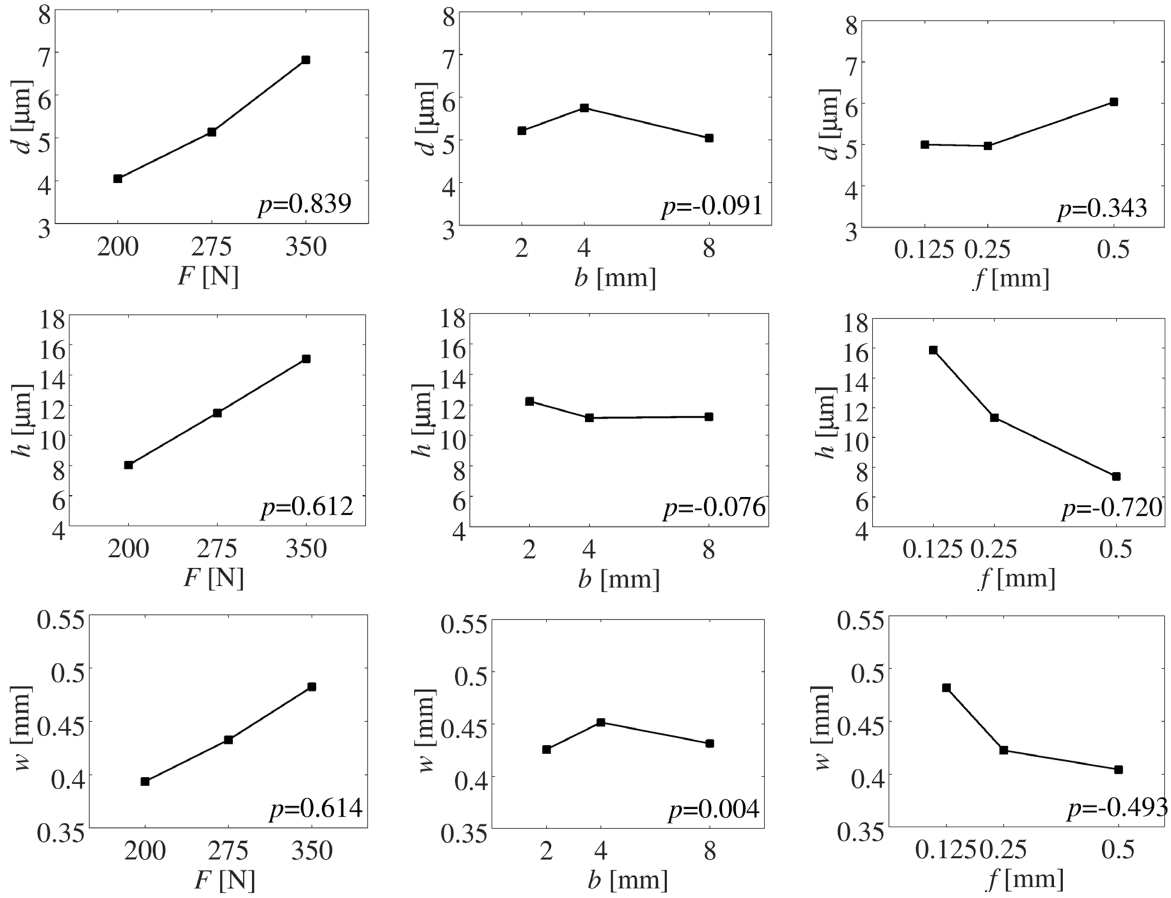

Fig. 5. Bulge depth *d*, height *h* and width *w* in relation to the burnishing force *F*, the burnishing width *b* and the burnishing feed *f* for the lateral burnishing bulge

Conclusion

Experimental investigations of single burnishing paths and burnishing areas were done. The length of the path *l*, the width of the area *b*, the feed *f* and the applied burnishing force *F* were varied. The resulting burnishing bulge in frontal direction to the path and in lateral direction of the area was characterized by its depth *d*, height *h* and width *w*. The following conclusions can be drawn for the investigated process and material parameters:

- frontal burnishing bulge
  - bulge is influenced by the burnishing force
  - higher burnishing forces increase bulge depth, height and width with a proven linear dependency
  - length of the burnishing path has no influence
- lateral burnishing bulge
  - bulge is influenced by the burnishing force and feed
  - higher burnishing forces increase bulge depth, height and width, but without a proven linear dependency
  - higher burnishing feed decrease bulge height and width, but without a proven linear dependency
  - width of the burnishing area has no influence

Further studies have to investigate a possible interaction between burnishing feed and force, as well as the bulge formation on other materials.

Acknowledgement

The research was funded by the European Union (European Social Fund) and the Free State of Saxony.

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