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Published in:
29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland

DOI:
10.1016/j.promfg.2020.01.132

Published: 01/01/2019

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Huuki, J., Laakso, S. V. A., & Ullah, R. (2019). Effect of tangential misalignment in ultrasonic burnishing. In *29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland* (Vol. 38, pp. 1540-1546). (Procedia Manufacturing). Elsevier. https://doi.org/10.1016/j.promfg.2020.01.132

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ScienceDirect

Procedia Manufacturing 38 (2019) 1540–1546

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

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Effect of tangential misalignment in ultrasonic burnishing

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Abstract

Ultrasonic burnishing is a surface finishing process that produces fine surface roughness, improved geometrical accuracy, high compressive residual stresses and increased hardness. The method is suitable for finishing dies or other double curvature surfaces and it does not require changing of the fixturing setup after a machining process. The method has not however become commonly used in industry, because the technology has not been extensively tested. Technological parameters in ultrasonic burnishing includes the surface speed, distance between consecutive passes (or in machining terms, feed) and contact force. Ultrasonic burnishing is based on forging at an ultrasonic frequency of over 20,000 impacts per second and there is no material removal associated with the process. The technological parameters have been tested and recommended values have been recorded for some common work materials. One important parameter is the tangential alignment of the burnishing tool in regard to the workpiece surface normal. This parameter is easy to control in turning operations or with planar surfaces, but with a double curved surface the control of the angle is more difficult. All the previous research has been done on cylindrical or planar workpiece and therefore the tangential misalignment or the sensitivity of the surface integrity regarding the tangential misalignment has not been studied. This paper investigates the effect of the tangential misalignment of the burnishing tool and the effect on surface integrity. The results show that ultrasonic burnishing is suitable method for finishing workpiece surfaces even with inclined tool angle. The ultrasonic burnishing produced a beneficial surface integrity state on the workpiece surface with hardened material and improved surface quality. The surface micro-hardness increased by 1.4-6.7 %. At the same time, the average surface roughness (Ra) values decreased by 50-85 % depending on the misalignment angle.

Keywords: Ultrasonic burnishing; Tangential Misalignment; Surface Integrity

1. Introduction

Surface roughness is a significant design specification that is known to have considerable influence on properties such as wear resistance and fatigue strength [1]. A smoother surface has a high wear resistance and better fatigue life [2,3]. Conventional methods, such as grinding, polishing and lapping are widely used finishing processes in

10.1016/j.promfg.2020.01.132

applications that require an excellent surface finish and dimensional accuracy. An alternative to the conventional methods is burnishing. Burnishing is a finishing process that is based on cold working i.e. forging the workpiece surface and levelling the peaks and crevices of the surface topography. There are four distinct methods of burnishing: roller burnishing, ball burnishing, diamond burnishing and ultrasonic burnishing. Burnishing processes differ from material removing processes like grinding or cutting, because burnishing doesn't remove material and burnishing produces compressive residual stresses to the workpiece surface [4]. Diamond burnishing has fully sliding contact between the tool and the workpiece. Korzynski et al. have actively researched diamond burnishing and the beneficial effects of diamond burnishing on surface integrity have been investigated in their article published in 2011 and 2013 [5,6]. Especially interesting results is that corrosion resistance of stainless steel improves after burnishing. Brostow et al. 2013 showed that using diamond burnishing before coating high speed steel tools (Vanadis 6), the thickness of coating increases and the microhardness is improved [7]. Roller and ball burnishing processes have rolling and sliding contact with the surface, and ultrasonic burnishing has interrupted sliding contact with the workpiece. Balland et al. 2013 showed that the effect of roller burnishing on the surface roughness and on the residual stress profile can be simulated using FEM [8]. FEM was used also in Yen et al. 2005 who showed that 2D-simulations produced better results than 3D-simulations, but 3D simulation predicted the surface roughness profile better than 2D-simulations [9]. El-Tayeb et al. 2007 investigated the effect of roller burnishing on Al6061 and concluded that burnishing force above 220 N produces over 35% improvement in surface roughness. The surface roughness increases with increasing rotation speed and the best results were obtained at 110 rpm [10]. There are multiple works also on ball burnishing and the effects on surface properties [11–14]. Ultrasonic burnishing is a relatively new surface enhancement process. The method is based on forging the workpiece surface at 20,000 impacts per second. The process principles are illustrated in Fig. 1.

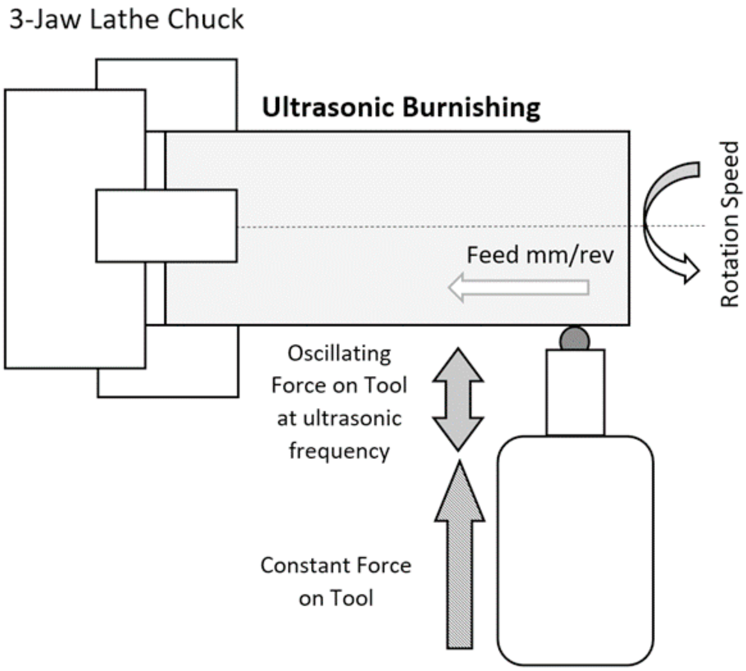

Fig. 1 Ultrasonic Burnishing Principles and Process Parameters.

The effect of the ultrasonic burnishing on workpiece geometry, hardness, residual stress state and surface roughness, and how workpiece material affects the process has been investigated in previous research [15–18]. The research showed that the method produces improved surface roughness, increased hardness, and favorable compressive residual stresses on the metal parts. It was concluded that ultrasonic burnishing produces higher compressive stresses and better surface finish compared with diamond burnishing.

Ultrasonic burnishing is especially an attractive method for finishing double curved surfaces in dies for example, since the finishing could be done without manual work and with the same setup as machining, thus reducing setup and production time. However, the method has not been tested in multiaxial cases, or the sensitivity of the process regarding the misalignment of the burnishing tool with respect to the workpiece surface tangent. Hence, the purpose of this study is to investigate the effect of tangential misalignment of the burnishing tool on the surface roughness and hardness in turning.

Nomenclature

κ	Tangential Misalignment of the Burnishing Tool

2. Materials and methods

2.1. Ultrasonic Burnishing

The ultrasonic burnishing equipment used in this study is a Hiqusa ultra burnishing system. The workpiece is 34CrNiMo6 steel of 88 mm diameter round bar. The burnishing equipment was installed on a lathe. The tangential misalignment angle κ of the tool (illustrated in Fig. 2) was varied between -45 and 45 degrees, and the angles were (-45, -20, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 20, 25, 30, 35, 40, 45). Misalignment angle is limited to ±45 degrees because of the size and geometry of the ultrasonic burnishing equipment. The misalignment angles were selected by varying the angle in 1-degree increments. Since no major changes were observed between 0 and 15 degrees, the increment was increased to 5-degrees. Negative misalignment angles were also tested to see if the effect is symmetric. Spindle speed was 80 rpm and feed of the burnishing tool was 0.05 mm/rev. The feed and spindle speed are selected to produce the best possible surface quality and the recommendations for these are given in Huuki 2013 [15].

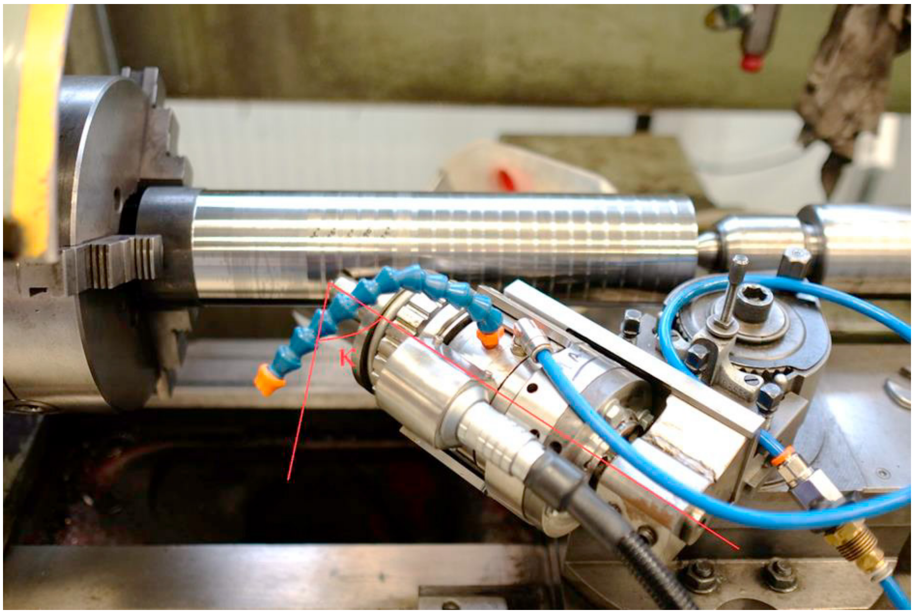

Fig. 2 Ultrasonic Burnishing Setup and Tangential Misalignment κ.

2.2. Hardness Testing

To investigate the fluctuation of the hardness among finished the surfaces produced by the variation of the burnishing tool misalignment angle, a Gnehm Brickers 220 hardness measuring equipment was employed and the Vicker V10 hardness scale was chosen. Hardness value is determined by measuring the length of diagonal and comparing it with V10 scale (98.07 N force) according to SFS-EN-ISO-6507-4. A wedge-shaped fixture held cylindrical workpiece at its position. Hardness was measured at three equally spaced points on the periphery of each 24 burnished bands.

2.3. Surface Roughness

The surface roughness is measured using Mahr MarSurf PS 10 surface roughness profiler. Each measurement was repeated twice, so three measurements for every surface batch with a different tangential misalignment angle.

3. Results

3.1. Ultrasonic Burnishing

There were no anomalies observed during the ultrasonic burnishing process with any tangential misalignment angle.

3.2. Hardness Testing

Fig. 3 presents the average hardness of each band along vertical axis and burnishing tool misalignment angle along the horizontal axis. Error bars represent the standard deviation of the measurement on each point. Standard deviation of the measurements was 1.1 % on average. Hardness of the machined surface is 371 HV10, so the increase in hardness after ultrasonic burnishing is minimum 1.4 % and maximum 6.7 %.

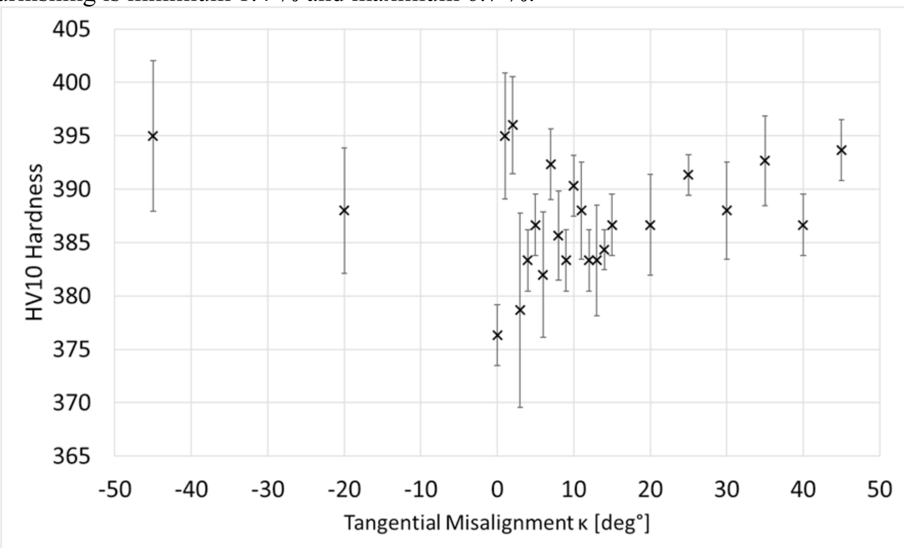

Fig. 3 Hardness Measurements.

3.3. Surface Roughness

The surface roughness measurements are shown in Fig. 4. The error bars represent the standard deviation. The standard deviation of the measurements was on average 6.9 %. The surface roughness of the machined surface is 1.442 µm, so the improvement of the roughness value was at the lowest 50 % and at the highest 85 %. Fig. 5 shows the surface roughness profiles for misalignment angles 0, 45 and for the machined surface.

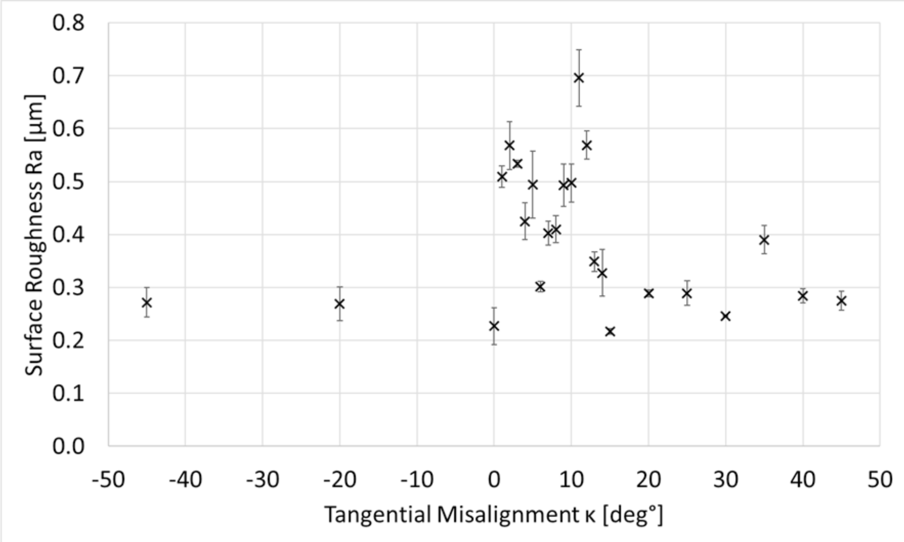

Fig. 4 Surface roughness measurements.

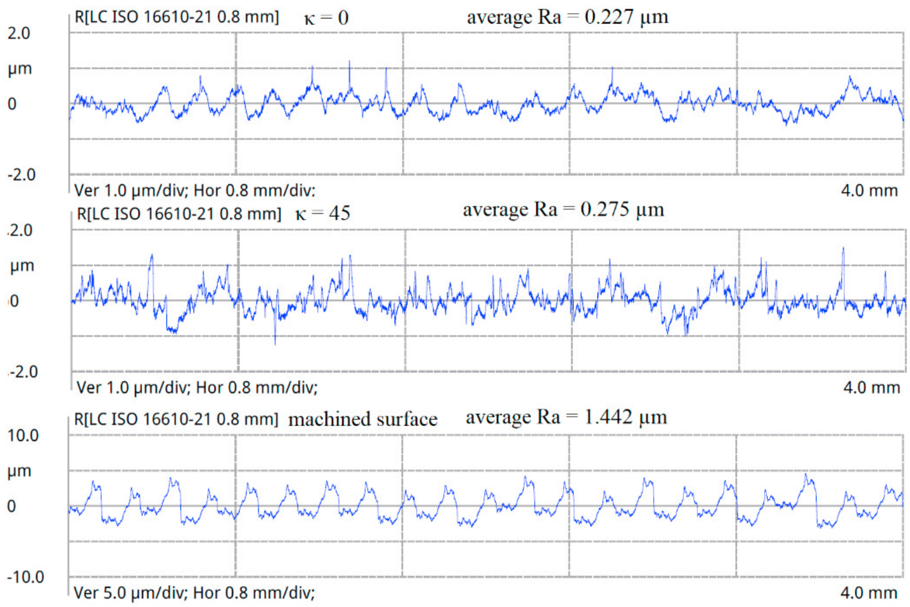

Fig. 5 Surface roughness profiles of misalignment angles 0 and 45 degrees, and the machined surface.

4. Discussion and conclusions

The key performance indicators of burnishing processes are increase of surface hardness, improvement of surface roughness and increase of compressive stresses on the surface. This research was done to evaluate the effect of tangential misalignment on the key performance indicators. The results from hardness testing and surface roughness measurements show clearly that the larger tangential misalignment does not have a negative effect on surface quality or hardness that was expected to happen. Quite the contrary, the hardness increases slightly and the surface quality improves significantly with over 15 degree tangential misalignment angles. However, there is some scatter in the results, so a clear relationship of surface integrity and misalignment angle cannot be seen. Compared with the machined surface, the surface hardness increased by 1.4-6.7 % and surface roughness improved by 50-85 % depending on the misalignment angle. Even though these results were unexpected, they were a positive surprise. The results indicate that ultrasonic burnishing can be used in multiaxial finishing of double curved surfaces, because in a situation where the burnishing tool is inclined in an angle on a cylindrical surface, the situation is mechanically comparable to a situation where the tool is orthogonal to a double curved surface. An example of such situation is finishing pre-machined dies in a 5-axis machining centre using the same fixturing setup as the machining. The ultrasonic burnishing method is applicable both in lathes and in milling machines since the tool is making the orthogonal forging motion against the surface and either tool or workpiece can move to change the position of the point of impact.

There are possible explanations for why the misalignment angle did not affect the results. First, the misalignment angle simply does not change the contact mechanism between the tool and the workpiece. Therefore, it should be investigated whether this is because there is relative sideways motion between the tool and the surface in both cases (misalignment angle 0 and 45), or there is not motion in either case. It is also possible that the relative movement is insignificant compared to the feed and rotational movement speeds.

For future work, similar experiment with different misalignment angles should be done with different workpiece materials to ensure that the results in this paper are not material specific. After this has been confirmed, multiaxial burnishing of a double curved surfaces can be tested.

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