Effects of ultrasonic burnishing on the surface quality of corrosion-resistant tool steel using a hard-carbon-coated burnishing tool

HUUKI Juha[1,a *], ULLAH Rizwan[1,b] and FANGNON Eric[1,c]

[1]Aalto University, Department of Mechanical Engineering, Puumiehenkuja 3, 02150 Espoo, Finland

[a]juha.huuki@aalto.fi, [b]rizwan.ullah@aalto.fi, [c]eric.a.fangnon@aalto.fi

Keywords: Ultrasonic Burnishing, Surface Quality, Carbon Coated Tool

Abstract. Ultrasonic burnishing is a relatively new and effective method for improving the surface finish of metal parts. Burnishing strongly affects the surface quality, improving surface properties such as, surface hardness and surface roughness. Previous studied have observed that changing some burnishing parameters significantly affects the burnished surface quality. In this research, using a carbon-coated burnishing tool, tangential misalignment angles were varied on a corrosion resistant tool steel that has not been previously investigated. Two different burnishing tools were used to study their effect on surface quality and surface hardness. The results revealed that coated tungsten carbide tool has produced superior surface finish compare to non-coated burnishing tool which is the new finding. It is rather surprising that surface roughness has not increased as it typically happens during burnishing but a clear surface roughness enhancement was observed. The results showed a clear improvement in surface roughness (80-86%), whereas surface hardness did not change significantly.

Introduction

Ball burnishing and other forms of burnishing methods have gained popularity in recent years, as they not only affect the workpiece surface but also improve both the physical and mechanical properties of turned parts [1]. The goal of all burnishing methods is to create surface layers of high quality to improve the surface properties of mechanical components, such as surface roughness, hardness residual stress, and microstructure in different applications that require an excellent surface finish and dimensional accuracy [2,3]. Such methods are mainly used on rotating components with high-quality requirements, such as automotive axles, bearing parts, or crankshafts [4].

In manufacturing industries, the burnishing process has proven to be an easy and economical surface enhancement technique in secondary operations like grinding, honing, and lapping [5]. The burnishing process leads to the plastic deformation of the work surface when it comes in contact with a highly polished and hardened tool known as a burnishing tool [5].

Ultrasonic burnishing is less well known than the roller, ball, or diamond methods. This modern method is used for finishing metal surfaces by forging at very high frequency. Forging is performed with a ball-shaped finishing head at extremely high ultrasonic frequency while the workpiece rotates along a fixed axis, as depicted by the schematic in Fig.1. A constant spring load is applied to the burnishing tool to keep it in contact with workpiece surface. The process removes no material from the workpiece. Instead, it causes plastic deformations on the part surface, thereby creating residual stresses and improving surface quality [6].

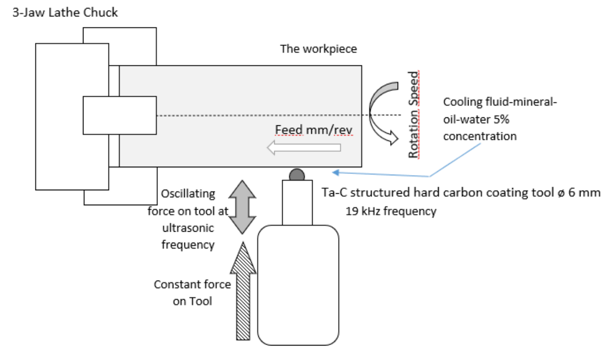

Fig.1. Schematic of the ultrasonic burnishing process.

Raza et al. recently published an extensive overview of past research on surface integrity in different burnishing processes, including ball burnishing, roller burnishing, and low plasticity burnishing (LPB) [5]. The authors found that carbon chromium, TiN coated EN31, tungsten carbide, high carbon and chromium steel, and HSS steel were all common roller materials reported in past research work. The burnishing process is mostly used to improve hardness, surface roughness, fatigue strength, corrosion resistance, wear resistance and microstructure properties, and to generate compressive residual stresses [5]. A ball burnishing tool consists of a hard ball constructed from hard materials. According to Raza et al., most researchers have used carbide material for the ball because of its high modulus of elasticity and high density. However other ball burnishing tool material is also used including alumina carbide, cemented carbide, silicon carbide, silicon nitride, ceramics, and carbon steel [5,6]. Moreover, as Prasad et al. state, most researchers have studied and optimized the burnishing process parameters on the surface roughness and surface hardness of ferrous and nonferrous metals, such as brass and aluminium alloys [5,6].

Little research work has been conducted on tangential misalignment or carbon-coated tools in ultrasonic burnishing, although many authors have examined burnishing methods, such as the ball, roller, or slide effect on material integrity [7-12]. Moreover, to our knowledge, no study has investigated the effect of ultrasonic burnishing on the surface quality of cylindrical stainless-steel workpieces with different tangential alignments a carbon-coated tool. Furthermore, based on our literature review, no researchers have used ultrasonic burnishing to finish Corrax material. The material is used in the mold industry and in different engineering parts [13]. For this reason, there is a clear need to evaluate the effect of ultrasonic burnishing on the surface finish in this context.

Methodology

HIQUSA ultrasonic burnishing equipment was used to burnish a workpiece manufactured from a corrosion resistant-tool steel with an initial hardness of 385 HV. As shown in Fig.2, ultrasonic burnishing was performed on the stainless steel, commercially available as Corrax. The workpiece was pre-machined from a diameter of 90 mm to 88 mm, with a length of 500 mm. The designations and typical compositions of the test material used are shown in Table 1. The test material is well-suited for mould-making parts and it exhibits excellent resistance to corrosion [13].

Table 1: The chemical compositions (wt%) of the tested work material.

Corrax						
C	**Si**	**Mn**	**Cr**	**Ni**	**Mo**	**Al**
0.03	**0.3**	**0.3**	**12.0**	**9.2**	**1.4**	**1.6**

Fig. 2, below, depicts both the HIQUSA ultra burnishing equipment used to undertake the burnishing process and the Tangential Misalignment Angle (TMA), kappa (κ). TMA is defined as the angle formed between the burnishing tool axis and axis of the shaft. For the tool oriented 90° to the shaft, TMA is considered as 0 and it can increase on either side - hence positive and negative TMA are possible. It is important to study TMAs, since in burnishing process, one semi-spherical (burnishing tool) and a cylindrical surface get in contact with each other and double curved surfaces [2] could form. Beside the possible effect on cylindricity, surface roughness can be vary significantly [2].

In our previous work [2], burnishing was performed on Stavax stainless steel using a wolfram carbide ball with a finishing head 6 mm in diameter. The Ta-C structured hard-carbon coated-tool used in this research is known commercially as BALINIT® MILUBIA [15]. Burnishing in this case was limited to a TMA range of 0°-45°. The burnishing parameters are shown in table 2. The ultrasonic burnishing parameters were 80 rpm for the spindle speed and 0.05 mm/rev for the feed, while forging was performed at a frequency of 19 kHz. The spring preload was 1.5 mm for the workpiece. A cutting fluid (filtered 5% oil-water emulsion) was used to cool the tool in the process.

Table 2. Burnishing process parameters.

Burnishing parameters	Ultrasonic burnishing
Force P	5.40 N
Frequency	19 kHz
Preload on the spring	1.5 mm
Feed	0.05 mm/rev
Speed	80 rpm

However, in the present work, the burnishing parameters were changed to 500 RPM and a ø 6 mm carbon-coated tool was used. The tool feed and burnishing frequency of the tool head were kept constant, as in Fig.1 [2]. With this configuration, burnishing was only possible at 0° TMA, while a higher TMA resulted in deteriorated surfaces.

Surface Roughness

MarSurf PS 10 apparatus was used to measure the surface roughness of the burnished bands along a cylindrical shaft. This equipment uses a stylus measuring probe and the cut-off length value is selected as 2.5 mm. The device was used to measure the roughness of both the pre-machined and burnished surfaces.

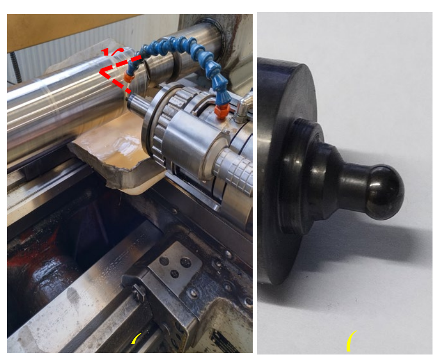

Fig. 2. Burnishing equipment: (a) tangential misalignment angle (TMA) κ, (b) carbon coated tool head.

Surface Hardness

Brickers-220 equipment was used to measure the surface hardness of the burnished bands along the circumference of the shaft. Each burnished band was approx. 5 mm in length. Hardness was measured five times at each location, which corresponded to a different tangential misalignment angle.

Results and Discussion

The test material surface after burnishing is shown in Fig. 3. The surface finish differences between the burnished surfaces produces by the Ta-C hard carbon coated tool (green) and the wolfram carbide tool (red) can be easily distinguished. This demonstrates that tool material and coating significantly affects the surface finish.

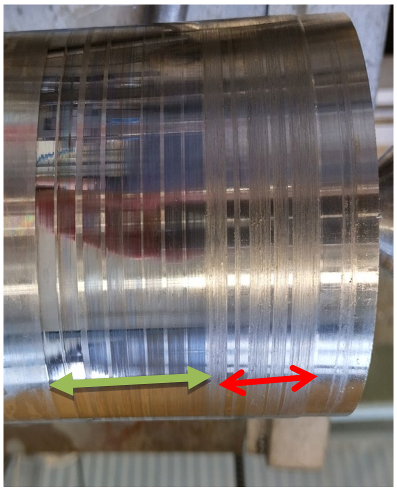

Fig. 3. Surface with carbon coated tool head (green arrow) and a wolfram tungsten carbide (red arrow).

Surface hardness.

The hardness of the machined (after the turning operation) shaft prior to burnishing was measured as 385 on the HV10 scale ± 15. The same value is 41 on the Rockwell C scale (HRC), which is comparable to the as-supplied hardness value provided by the manufacturer of Corrax [13].

The use of coated tools during burnishing, resulted in a rather uniform surface hardness with both positive and negative tangential misalignment angles (TMAs), implying that TMAs has exert no effect on surface hardness (Fig 4). This finding contrasts with the results for Stavax (a stainless steel with a different composition from Corrax) where surface hardness increased (1.5-3.6%) compared to a machined but unburnished surface. This effect could be associated with material behaviour or the use of coated tools and therefore must be further investigated. However, ultrasonic burnishing has been found increase surface hardness by 6.8 % for 34CrNiMo4 steel [14].

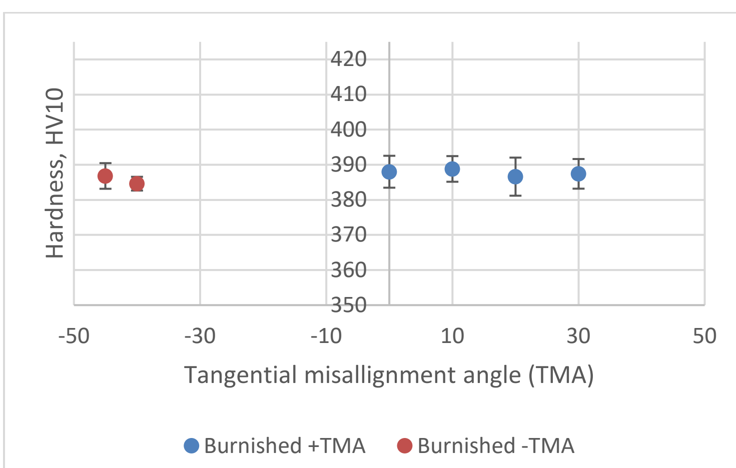

Fig. 4. Surface hardness measured on the Rockwell HRC scale for various test-material tangential misalignment angles.

Surface roughness.

For purposes of comparison, the surface roughness of an unburnished and machined (turning only) surface was measured as 1.6 µm. Surface roughness appeared to be affected by changing TMAs, where 0 degrees yielded a rough surface compared to higher TMAs. The increase in surface roughness compared to the machined surface was a minimum of 80% and maximum of 86%, which is an extremely positive influence. Overall, surface roughness, which reflects superior surface quality, improved significantly compared to the machined surface. This result is comparable to the burnishing of Stavax [2]. Fig 5 demonstrates the significant improvement in surface roughness achieved by using the coated tool. These findings are also in accordance those reported in the literature on the effect of burnishing on surface quality [2,7].

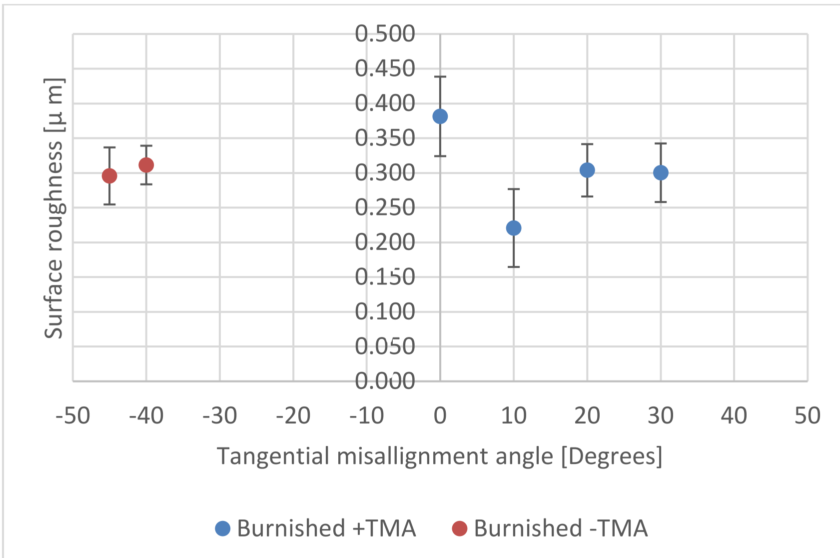

Fig. 5. Surface roughness of Corrax material (Ra).

Summary

Ultrasonic burnishing is a finishing process which imparts beneficial compressive residual stresses and enhanced surface properties. The method is especially suited for shafts and mechanical parts but can be implemented on flat-face surfaces as well. In this study, ultrasonic burnishing was applied to Corrax (a stainless-steel material) using coated tools. The study analysed the effects of changing the tangential misalignment angle (TMA) on surface hardness and on surface roughness. The following conclusions can be drawn:

- For the specific case of Corrax, ultrasonic burnishing exerted very little effect on surface hardness, which is an unusual burnishing behaviour that requires further investigation.
- Coated burnishing tools enhanced surface roughness by 80-86% which is comparable with previous results.
- Performing the ultrasonic burnishing operation with the Ta-C structured hard-carbon coated-tool 6 mm diameter and 19 kHz frequency, the Corrax material is a suitable combination for the application of the process in terms of surface quality enhancement.
- Ultrasonic burnishing treatment process with tungsten carbide (Ta-C) structured hard carbon coated tool has resulted much superior surface quality compared to non-coated burnishing tool.

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