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Citation for the original published paper (version of record):
Huuki, J., Ullah, R., Laakso, S. (2020). Process limitation of ultrasonic burnishing for commercially available martensitic stainless
steel. Procedia Manufacturing, 51: 885-889. http://dx.doi.org/10.1016/j.promfg.2020.10.124

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 51 (2020) 885–889

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021)
15-18 June 2021, Athens, Greece.

# Process limitation of ultrasonic burnishing for commercially available martensitic stainless steel

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## Abstract

Ultrasonic burnishing is attracting ever-greater interest as a surface finishing process. Although the popularity of this method in manufacturing industry remains limited, research is being conducted to explore both the detailed aspects and the limitations of this method. Tangential misalignment is one of most influential parameters in determining the mechanical properties induced by ultrasonic burnishing. This study investigates the effect of tangential misalignment on the ultrasonic burnishing of martensitic stainless steel (Stavax) and the surface integrity of the processed workpiece. Both negative and positive misalignments (from 0° to 5°) angles were tested. Macro hardness, instrumental micro hardness and surface roughnesses were measured. The results revealed that at higher tangential misalignment (>5° and along the negative side), ultrasonic burnishing cannot be performed for this material. It was found that with an increase in misalignment, hardness and surface roughness increased. Instrumental micro hardness measured from the burnished end, through the depth, revealed that hardness started decreasing from 60 µm towards the center of shaft. This indicates that beside ultrasonic burnishing has induced surface hardness, effect of hardness has been induced up to 60 µm. Considering the previous literature on ultrasonic burnishing, it appears that the potential of ultrasonic burnishing has some limitations depending on the material properties.



*Keywords:* Ultrasonic burnishing, tangential misalignment, martensitic stainless steel, surface integrity, hardness, surface roughness

## 1. Introduction

Surface finish plays vital role in influencing functional characteristics such as wear resistance, corrosion resistance, fatigue strength, and power loss resulting from friction [1, 2]. Moreover, a smoother surface has higher wear resistance and better fatigue life; i.e., it has a longer cycle life as a result of this compressive stress action [3, 4]. Burnishing is used in areas like the automobile, aircraft, defense, machine tool, hydraulic and pneumatic equipment and home appliances sectors [5].

In applications that require an excellent surface finish and dimensional accuracy, conventional methods are widely used in finishing processes such as grinding. However, the quality of the finished surfaces of mechanical components is increasingly becoming a significant factor in engineering solutions, and high-quality properties are more difficult to achieve with traditional processes [6,7,8]. Burnishing is one finishing technique that serves as an alternative to traditional grinding processes [9]. Burnishing is considered a cold-working finishing process, differing from other cold-working surface -treatment processes such as shot peening and sandblasting in that it produces a good surface finish and also induces residual compressive stresses in the metallic surface layers [7, 8]. As Nguyen TT et al. state, many researchers have explored the impacts of processing conditions on the machining targets for different burnishing processes.

Moreover, the burnishing processes are widely applied in the manufacturing of the cylindrical, spherical, concave, and convex surfaces of machined components. Ultrasonic burnishing has traditionally been used to finish hard and brittle


10.1016/j.promfg.2020.10.124

materials because ultrasonic processing is not affected by material hardness. The ultrasonic utilized in finishing has mainly been performed with manual ultrasonic machines that have been used to finish pieces of material with a small surface area. The present study examines the applicability of ultrasonic burnishing as a finishing method, as little research work has been conducted on surfaces that have been finished specifically with ultrasonic burnishing. The present work aims to study the effects of ultrasonic burnishing on surface integrity, especially the hardness and surface roughness of metal surfaces, with different tangential alignments of the burnishing tool. According to Priyadarsini et al., surface roughness and microhardness have been the most popular variables measured in previous ball burnishing related research [10].

Priyadarsini et al., recently presented an overview of past research on surface integrity in burnishing [10]. The results of this meta-study show burnishing to be an effective technique for improving surface properties. For example, the authors demonstrate how burnishing processes can improve the surface

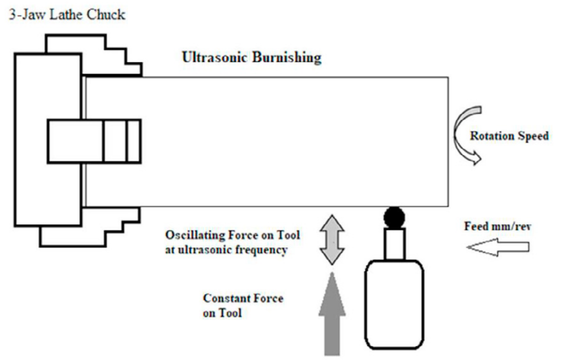


Figure 1 Sketch of the ultrasonic burnishing process on a lathe and Processes Parameters

quality of metal parts. Ultrasonic burnishing is a no-chip surface treatment method for improving the surface quality of mechanical parts. The method is relatively new, and it based on forging the workpiece surface at 20,000 impacts per second [11]. A sketch of the ultrasonic burnishing process on a lathe is shown in Fig. 1. The effect of ultrasonic burnishing on workpiece integrity, i.e hardness, surface roughness, residual stress state and, and how workpiece material affects the process has been investigated in previous research [11–14]. This research has demonstrated that the method increases hardness and produces improved surface roughness and favorable compressive residual stresses on the metal parts. Moreover, a number of studies have investigated the influence of burnishing parameters on the residual stress and fatigue strength of the workpiece [15]. These studies have found that the process enhances surface quality and hardness, which improves wear resistance. In addition, Hocheng and Kuo have demonstrated that burnishing methods are suitable for processing plane-shaped geometries [16]. Furthermore, Buldum B.B et al., have successfully implemented a ball burnishing technique for surface quality development experiments on steel, aluminum, polymer, titanium or nickel workpiece material [17]. However, they found that the use of the method on magnesium made workpieces was limited. Some research has previously been conducted on the effects of ultrasonic burnishing on surface integrity, but no findings exist on the effects of the tangential misalignment of the burnishing tool and the effect on surface integrity for martensitic stainless steel. Travieso-Rodríguez et al. demonstrated that the ball burnishing direction and the curvature radius were the most significant parameters in their experiment [18]. They also showed that the ball burnishing process was an effective method for improving the surface finish of workpieces of different materials and geometric configurations with a certain level of complexity. Travieso-Rodríguez et al. showed that the surface quality improved with the vibration-assisted ball-burnishing process [19]. However, ultrasonic burnishing has not been tested in multiaxial cases, and little research work has been conducted on tangential misalignment in ultrasonic burnishing. Therefore, it is crucial to further assess the influence of misalignment on surface integrity. The present study thus focuses on the effect of tangential misalignment on the ultrasonic burnishing of martensitic stainless steel (Stavax) and the surface integrity of the processed workpiece.

## 2. Methodology

The workpiece in the present study was an round bar of martensitic stainless steel 88 mm in diameter (Stavax). This material was selected because of its importance in the mold industry, especially in the injection molding process. The chemical composition of Stavax, which is delivered in an annealed state, is shown in Table 1. The ultrasonic burnishing equipment used in this study was a Hiqusa ultra burnishing system. The burnishing equipment was installed on a lathe using a lubricated tungsten carbide ball 6 mm in diameter, as shown in Figure 2.

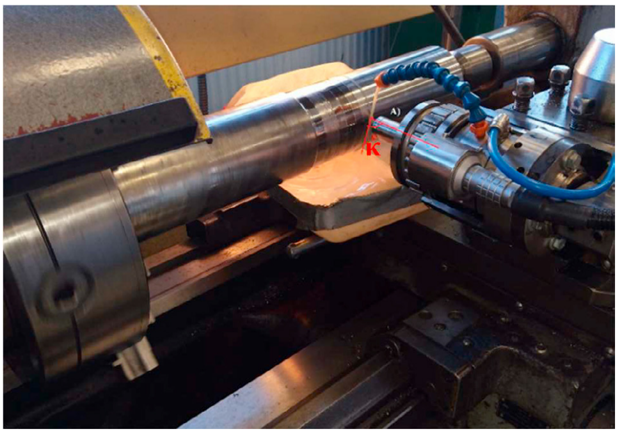


Figure 2: Ultrasonic Burnishing representation of the experimental set-up: a) tool, Tangential Misalignment κ.

Table 1: Chemical composition of Stavax

| Element | C | Si | Mn | Cr | V |
|---|---|---|---|---|---|
| percentage | 0.38 | 0.90 | 0.50 | 13.60 | 0.30 |

The tangential misalignment angle, κ-, of the tool (illustrated in Fig. 2) was varied between 0 and 5 degrees, (0°, 1°, 2°, 3°, 4° and 5°). The misalignment angles were selected by varying the angle in 1-degree increments. The spindle speed was 80 rpm and the feed of the burnishing tool was 0.05 mm/rev. Ultrasonic burnishing was performed for a different set of parameters, such as the feed and spindle speed, to produce the best possible surface quality according to the recommendations provided in Huuki 2013 [11].

### *2.1. Surface roughness measurement*

Surface roughness was measured on MarSurf PS 10 equipment by Mahr Gmbh, using the stylus type measurement method. The cut-off length was kept at 2.5 mm.

### *2.2. Hardness measurement*

Hardness was measured on the top surface of the burnished bands (circumference of shaft) using Brickers-220 equipment. No mechanical preparation (grinding/polishing) was performed prior to measuring hardness along the machined and burnished surface. The hardness value was calculated by measuring the length of the diagonal on a V10 scale (98.07 N force) according to the SFS-EN-ISO-6507-4 standard. Hardness was measured at three locations in each burnished band representing TMAs.

Small section was cut from the shaft at 0° TMA and the instrumental hardness was measured along the depth from burnished end, using csm Micro Combi Tester. With this equipment load of 100 µN was applied using linear loading at penetration rate of 200 µN. Sample was ground using SiC paper (FEPA grit size 4000) and subsequently polished with 3 and 1 µm diamond paste as the final preparation step. 4 columns, each consisting of 10 measurement points each, were selected at horizontal inter distance of 50 µm whereas vertical distance was maintained as 25 µm. First measurement was selected at 10 µm from burnished end.

## 3. Results

### *3.1. Surface roughness*

Figure 3 presents surface roughness (Ra) measured along the circumference of the shaft for five tangential misalignment angles (TMA). The error bars indicate the standard deviation for each measurement. The machined surface without burnishing had a roughness value of 1.85 µm with a standard deviation (SD) of 0.11 µm. In figure 3, only those TMAs are presented where burnishing is feasible. At a higher TMA, the surface distortions are so acute that they can potentially lead to the breaking of the burnishing tool.

The least surface roughness was encountered at a TMA of 0°. By contrast, roughness increased by almost a factor of three for larger TMAs. Surface distortions at a TMA greater than 5° are large enough to cause the burnished surface to deteriorate more than the machined surface, thus making burnishing impractical. It was also observed that at a negative TMA, burnishing cannot be performed at all, i.e. the surface was rougher than the machined surface. Compared to machined surface roughness, ultrasonic burnishing increased surface roughness by a minimum of 26.7% at 4° and 79% at 0° TMA.

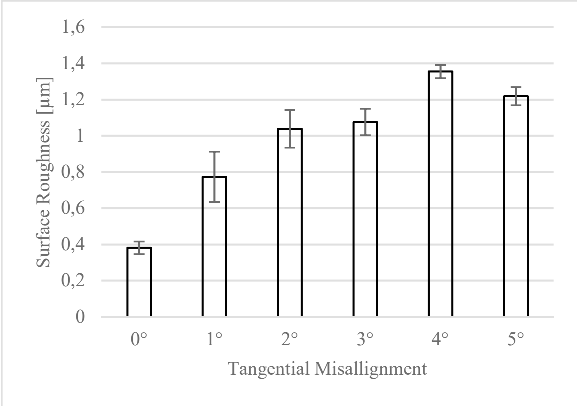


Figure 3 Surface roughness regarding shaft tangential misalignment angles

### *3.2. Hardness measurement*

Hardness measured on HV10 scale, along the circumference of each of burnished bands is presented in Figure 4. The error bars represent the standard deviation. The machined surface hardness was measured as 258. Ultrasonic burnishing increased hardness by a minimum of 12% at TMA of 2° and maximum of 28.8 % at a TMA of 5°. The average standard deviation was 6.3 Vickers hardness.

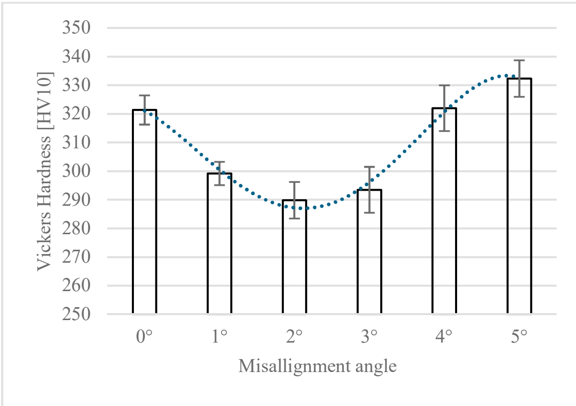


Figure 4: Surface hardness measured at circumference of burnished bands

The extent of increase of hardness along depth, as a result of burnishing was determined by measuring instrumental micro hardness using 100 µN load and results are presented in Figure 5. Hardness has reduced by 18% from the first measured point at 10 µm from burnished end to average Vickers hardness of 362.

Surface hardness increase with TMA is evident from Fig 4. On the other hand, a decrease in hardness is visible from the burnished end to the center of the shaft up to depth of 60 µm from burnished end. It is possible that hardness induced effect is lower than 60 µm since SD bars are much larger for initial measurement points. Nevertheless, a decreasing trend with the depth is noticeable. In this way burnishing has positively influenced surface properties.

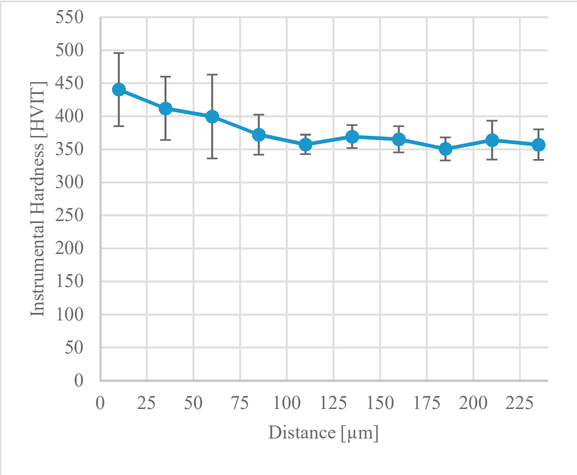


Figure 5: Instrumental hardness (HVIT) measured at various depths from burnished end

## 4. Discussion

Ultrasonic burnishing is a modern finishing process commonly applied to improve the surface integrity, i.e. surface roughness, hardness residual stress, microstructure of a mechanical component. This study explored the process limitation of burnishing as a finishing operation. The highest surface finish was achieved at a TMA of 0° because the burnishing tool symmetrically deformed the surface material. For higher TMAs, the deformed surface might have resulted in non-symmetrical deformation, thereby increasing the surface roughness. The study established a clear effect for the TMA on the surface properties of STAVAX tool steel. Surface hardness also fluctuate with TMA, but no distinct relationship is observed in this regard.

A higher surface finish with increased hardness as a result of burnishing is generally considered as the desired output. Results pointed out that ultrasonic burnishing has yielded best surface properties at TMA of 0°, for STAVAX tool steel in annealed condition.

It was expected that surface roughness and surface hardness will not vary with TMA for all materials, as was observed by Huuki et al. for 34CrNiMo6 steel [20] but results of this study have indicated otherwise. Typically, material is heat treated before the burnishing operation, and since this study processed soft annealed STAVAX tool steel, it is possible that the high ductility of the material hindered burnishing possibility. It appears so that material properties (ductility, friction coefficient, chemical reactivity) and process parameter can limit the possibility of burnishing. It is also suspected that friction coefficient might vary with TMA.

As TMA is increased, friction coefficient is so high that it tears the material by severe plastic deformations, which might explain why burnishing is not possible at higher TMA. However, this has not yet been approved by the experiments. A good design of experiment (DOE) can perhaps better substantiate the contribution of each parameter to final surface properties achieved.

This study has proven that ultrasonic burnishing can be done in annealed condition, but this is limited by TMA. Results imply that burnishing is sensitive to the misalignment of the shaft and therefore it must be measured before performing the burnishing process. It can be asserted that ultrasonic burnishing can produce different surface properties depending on material properties and the TMA can significantly affect the efficacy of the burnishing process.

## 5. Conclusions

According to this study, the following conclusions may be drawn:

- Ultrasonic burnishing can substantially improve surface finish (a maximum of 79 %) and surface hardness (maximum of 79 %) and surface hardness (maximum of 28.8 %) from machined surface.
- Effects of ultrasonic burnishing can cause surface hardness to increase up to 60 µm.
- Material properties (microstructure, constituents, heat treatment etc.) can significantly affect the ability of material to be burnished.
- STAVAX tool steel can be burnished in soft annealed state with TMA fluctuation of 0-5° with optimized results achieved at 0° TMA.
- Tangential misalignment affects surface finish in linear fashion and surface hardness with a non-uniform trend.

## Future recommendation

Next step could be the heat treatment of the material and analyzing effect of burnishing process parameters on surface properties.

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