ANALYSIS OF TOPOGRAPHIC CHANGE BY SLIDE BURNISHING OF C45 STEEL SURFACE MILLED WITH VARIABLE NUMBER OF INSERTS

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Abstract
The burnishing process's positive changes in the material's properties are measured with different responses. Roughness, stress, and microstructure changes are the main indicators of the internal and external factors faced by the material. Burnishing process as a post-process of critical components to enhance different properties performed by applying pressure on the material to deform plastically for the expected properties enhancement is used in different industries. In this experimental work, C45 steel was face milled by single and multiple-inserts and burnished with a 6mm diameter synthetic diamond ball to study the effect of burnishing force on the surface topography. 3D roughness parameters were used as response parameters measured before and after the burnishing process by AltiSurf 520 of Altimet as they are more representative of topographic changes by different machining processes and procedures than profile roughness parameters. Roughness was reduced significantly after the burnishing process in both cases and a decreasing trend was observed when compared at the same burnishing force.

Keywords: *topographic study, surface roughness, 3D roughness, burnishing process, diamond ball*

1. Introduction

Burnishing process is a post-process that ensures the material to have a good surface finish with improved mechanical and many other properties. These changes are achieved by plastically deforming the randomly distributed material roughness by applying a controlled burnishing parameter using a hard burnishing tool. This process can be applied to milled, turned, and other types of surfaces which require post-processing. Its chip-less and no or minimum cooling requirement characteristics make it an environmentally friendly machining process by avoiding material west and hazardous constituent diffusion (Varga et al., 2023). The final burnished surface quality heavily depends on the initial roughness (Revankar et al., 2014). This means that the initial machining parameters generate a variety of surface roughness characteristics. Isotropic or anisotropic surface is one example of surface characteristics generated by different machining types. One key decision-making moment is whether to use a single or multi-insert cutter while face milling as it affects the surface finish.

The number of engaged cutting edges influences the feed rate or material removal rate which can also influence other machining properties (Khawaja et al., 2021). Multi-insert tools typically offer a higher feed rate capability due to their multiple cutting edges, resulting in shorter machining times and increased productivity. The ability to engage multiple cutting edges simultaneously allows for higher material removal rates and reduced cycle times, making multi-insert tools a preferred choice for high-speed machining applications. The cutting force is distributed equally to all inserts in the case of multi-insert cutter. This gives it an advantage over a single-insert cutter in reducing vibration during machining. As a result, tool life, surface finish generally machining performance are affected when using a cutter with single or multi-insert.

Most research on the surface finish of machined products uses 2D profile characterization which fails to provide areal information. This problem is due to the nature of evaluating the profile surface roughness on the profile. To solve this problem ISO/TC 213 worked on establishing an aerial surface roughness characterization performed on the sampling area (Blateyron, 2013). In 2002 ISO released an areal surface topography standard ISO 25178 that deals with 3D areal roughness (Jiang et al., 2007). The advantage of 3D roughness parameters over 2D profile roughness parameters is the ability to capture more detailed surface characteristics and variations. 3D roughness parameters consider not only the height variations along a profile but also the spatial distribution and texture of the surface. These provide a more comprehensive understanding of surface topography. The addition of dimensionality can lead to more accurate analysis and prediction of surface behavior in various applications such as manufacturing, tribology, and quality control.

(Swirad, 2023) studied areal surface texture changes of insert face-milled and grounded surfaces due to ball burnishing. His finding indicates that ball burnishing showed a decrease in surface amplitude. successive milling and burnishing processes experiment conducted by (Grigoras et al., 2016) shows increased burnishing parameters result in a general percentage improvement of surface roughness. They mentioned that they used CCMT inserts with a tip radius of 0.8 mm but not how many inserts were used. Another research by (El-Khabeery et al., 2001) studied quality improvement of sculptured surfaces milled with a ball-end cutter. A larger radial depth of cut while milling and a small radial depth during burnishing produced acceptable 2D profile surface roughness. (Lopez et al., 2005) also studied the effect of roller burnishing parameters on surface integrity after the milling process. Arithmetic mean roughness (Ra) was used to evaluate the roughness and milling process settings and machining parameters were not given. Lots of combined milling and burnishing processes for surface roughness modification literature are available but 3D areal topography evaluation with different milling cutters is scarce.

As mentioned in the introductory paragraph burnishing process is mainly to deform peaks of the surface plastically as a result a smooth surface and other enhanced properties can be achieved. During this process, even though all process parameters influence the desired output, burnishing force is one of the most reported dominant parameters (Saldana-Robles et al., 2018; Basak et al., 2009; Revankar et al., 2014; Hassan et al., 1996). The same research papers highlighted that up to a certain level depending on the material's elastic and plastic properties, its effect on surface roughness is positive till exaggerated material flow starts due to excessive force. The effect of varying burnishing force and initial surface's roughness produced by face milling the surface using single and double insert on topography changes was studied in this research work. This will give comprehensive understanding on initial surface's effect produced by different milling setup on burnished surface.

2. Experimental setup and methodology

To study the effect of the initial surface in this case face milled surface due to the burnishing process, two initial surface types were used. Medium carbon steel called C45 was milled by two different milling setups. The first setup used 250 m/min speed with 1000 rpm spindle speed based on the cutter diameter (80 mm) holding a single insert, 0.21 mm tool feed, and 1 mm depth of cut. Everything was the same for the second milling setup except for using a cutter with two inserts. Speed and feed were selected based on cutter and insert specification. The workpieces were then burnished with the same burnishing parameters of 0.05 m/min feed and one pass except the varied three different kinds of burnishing forces. Different initial surfaces created by different milling strategy and varied burnishing forces experimental setup are used to study their impact on the surface quality. As shown in *Figure 1* 3D roughness measurements were taken before and after the burnishing.

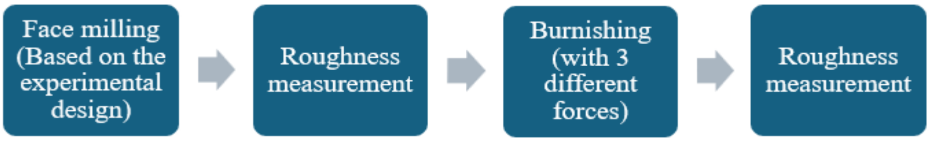

Figure 1. *Experimental procedure*

2.1. Milling and burnishing procedures

C45 (medium carbon steel) machined to a size and shape shown in *Figure 2* widely applied in construction and automotive industries was used in this experiment. Two holes were drilled to fix the workpieces over the force sensor used to control the burnishing force. Each workpiece contains three burnishing areas enough (8 mm × 8 mm) to measure areal topography parameters.

Perfect Jet MCV-M8 CNC milling machine located in the Institute of Manufacturing Science at Miskolc University was used to face mill and burnish the surfaces. A milling head R252.44-080027-1SM was used to hold an 80 mm R200-068Q27-12L 609902 SANDVIK cutter and a modified burnishing tool holder. RCKT 1204M0-PM 4230 inserts were used as per the experimental plan for each surface spindle running at 1000 rpm. The 3 mm radius burnishing tool followed a parallel burnishing path which is perpendicular to the milling direction at the center and deviates as it moves to the two sides.

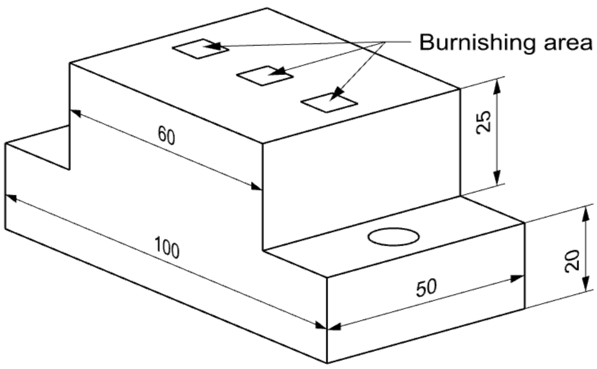

Figure 2*. Workpiece geometry and burnishing areas*

2.2. Measurements

The successful implementation of the modified burnishing tool in the previous author's (Frezgi et al., 2022) experiments paved the way for its application in this study. The machining strategy involved precise control of the burnishing force, monitored with a Kistler 9257A force sensor and signal processing charge amplifier. Integration of the NI Compact DAQ 9171 four-channel signal acquisition with LabView software enabled real-time data display and control, improving the accuracy and efficiency of the experimental setup. SAE 15W-40 traditional lubrication oil was used to minimize friction and ensure optimal performance during burnishing.

Table 1

Measured areal surface topography parameters

Measured values	**Sq (μm)**	**Sv(μm)**	**Sz(μm)**	**Sa(μm)**
Milled with single-inserts				
	1.67	7.94	12.2	1.24
Single-Insert milled and Burnished				
60 N	0.636	4.67	7.41	0.397
80 N	0.348	2.45	4.96	0.25
100 N	0.379	2.74	5.23	0.28
Milled with multi-inserts				
	1.6	7.87	16	1.25
Multi-Insert milled and Burnished				
60 N	0.446	1.98	3.82	0.375
80 N	0.28	1.92	3.93	0.217
100 N	0.272	1.25	2.96	0.212

The milled and burnished surface underwent 3D-dimensional topography analysis to study the effect of initial surface roughness and different force levels using the AltiSurf 520 surface measuring instrument. It is equipped with a CL2 confocal chromatic sensor and MG140 magnifier. Surface roughness assessment based on 3D surface topography parameters was carried out using the Altimap software from Digital Surf. The analysis followed ISO 25178 standards, utilizing a 4 mm sampling length and 0.8 mm cut-off for measuring and evaluating surface characteristics.

3. Result and discussion

Due to its accurate and comprehensive characterization of roughness, topography surface roughness is used in this research work to measure different roughness types. The height parameters mainly refer to the topographical characteristics related to how far a point on the surface is from the average plane. In simpler terms, they help to understand whether a surface is raised or lowered in elevation. Root mean square (Sq), Maximum pit height (Sv), Maximum height (Sz), and Arithmetic mean height (Sa) measured values using AltiSurf 520 are presented in *Table 1* for milled and burnished surfaces.

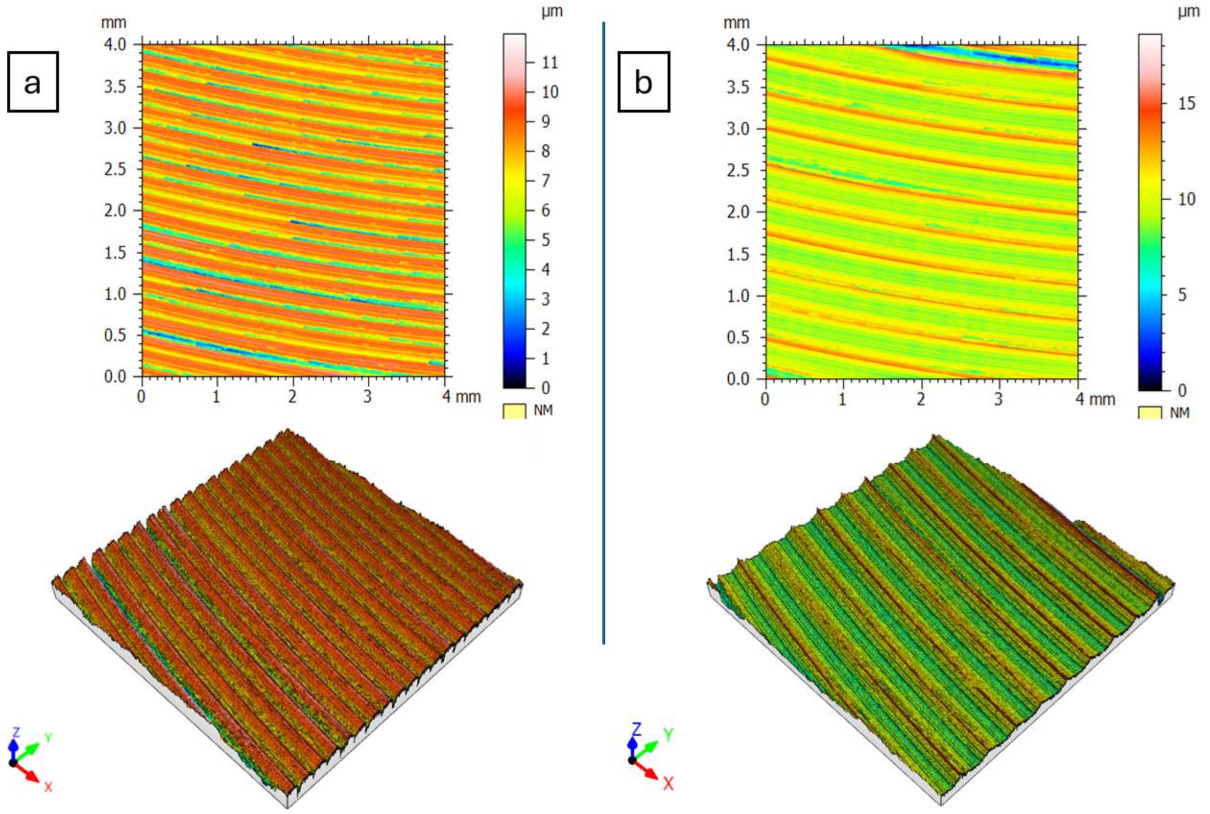

Figure 3. *2D and 3D view of measured area a) single-insert face milled b) multi-insert face milled*

In successive machining processes, each machining stage quality affects the next stag's machining time, quality, and other response parameters. For example, face-milled, and ground surfaces provide different post-processing challenges to achieve the final desired quality. In this research work surface was face milled by the cutter with single and double inserts. The feed rate increases with an increasing number of inserts, and this is clearly shown in terms of insert marks (periodicity) on the surface in *Figure 3 a* and *b*. In both faces milled with single-insert cutter and multi-insert cutter categories 3D surface topography parameters were decreased. These were true for all surfaces burnished by three different burnishing forces.

As shown in *Figure 4* roughness after the burnishing process was reduced for all the surfaces compared to the initial milled surface by single-insert cutter. This assures roughness modification by burnishing process for all measured parameters irrespective of initial roughness condition. When we check and compare the degree of modification by the three burnishing forces, surface burnished by 80 N and 100 N are smoother than surface burnished by 60 N. This tells us the applied 60 N force was not strong enough to deform all the peaks plastically for a smoother finish. In addition to this, the surface burnished by 80 N showed reduced roughness than the surface burnished by 100 N. Theoretically, when the burnishing force is very high, the surface can be plowed by the tool, and as a result rougher surface can be generated. For all measured responses, the roughness was decreased till the force increased to 100 N which changed the decreasing trend to increasing. However, we cannot conclude by the mentioned theoretical reason because there is not enough additional data on higher burnishing forces to give a full picture.

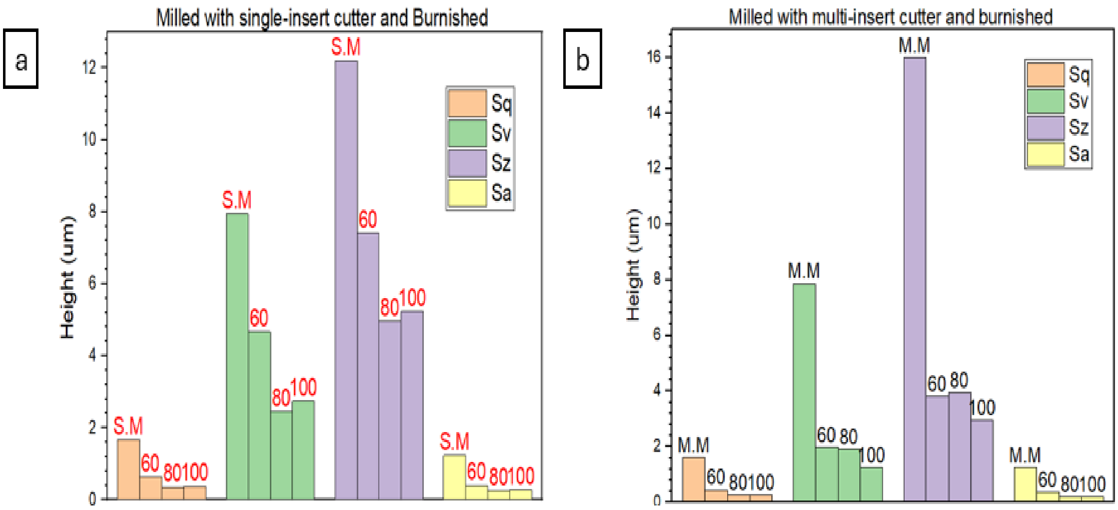

Figure 4. *Roughness height of measured parameters a) milled with single-insert cutter and burnished b) milled with multi-insert cutter and burnished*

In the case of the face milling process with a multi-insert cutter *Figure 4 b*, all topography height parameters decreased after the burnishing process by all used burnishing forces. Like in the single-insert cutter case, the burnishing process modified the roughness of the surface face milled by a multi-insert cutter. The applied burnishing force has a decreasing effect on Sv when increased from 60 N to 100 N changed from 1.98 um to 1.25 um. This indicates the pit height decreased when the burnishing force increased by filling the value with the deformed peak materials. Sz value change due to the burnishing force changes is not clear as it increased when the force increased to 80 N by a small amount (2.88%) and decreased again when burnished by 100 N force. Arithmetic mean height (Sa) and root mean square height (Sq) are more or less similar as they both measure height from the mean plane. In this experiment, they showed a decreasing trend as the force increased. This expresses peaks, and valley height from the mean plane decreases as the plastically deformed peaks fill the valley.

To compare topography roughness by the face milling strategy, response parameters of the surface milled by single-insert cutter and multi-insert burnished by the same burnishing force are compared. The line graphs in *Figure 5* illustrate the effect of changing the insert number from single to multi on smoothing the surface. For all used burnishing forces, the roughness value of all measured height parameters showed a decreased trend. 60 N and 100 N burnishing forces' higher slope indicates the significance of the change for Sz and Sv. All surfaces' parameters burnished by 80 N force and Sa and Sq values for all the surfaces show small slop that clarifies the change significance.

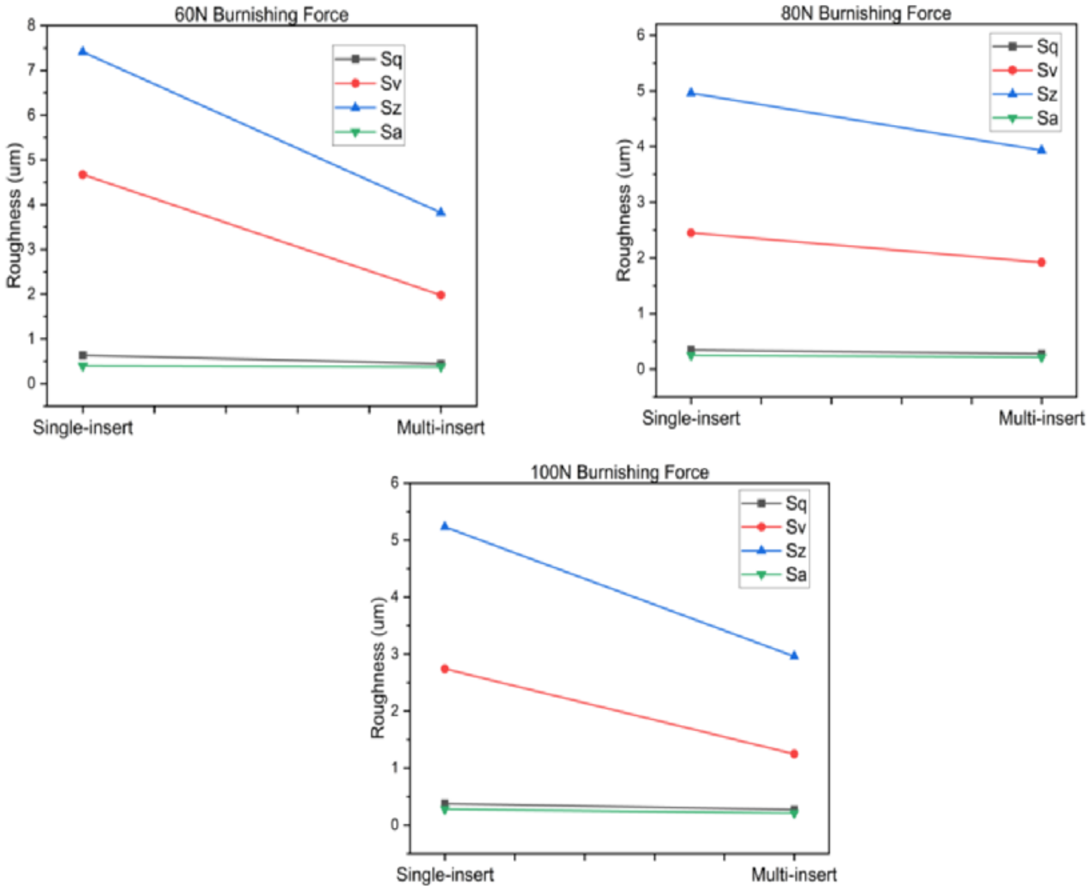

Figure 5. *Roughness comparison due to face milling strategy when the force is constant.*

4. Conclusion

Surfaces face milled by single and multi-insert cutters were burnished by three different burnishing forces to study the effect of milling strategy and changing the burnishing force on topography roughness. Based on the findings of this study, it can be concluded that the use of both single-insert and multi-insert face milling cutters resulted in decreased roughness on all measured response parameters after the burnishing process. However, there were differences observed in the roughness changes when different burnishing forces were applied.

Specifically, when comparing the effects of burnishing by 100N burnishing force resulted in rougher topography for the single-insert milled surface compared to the other two forces. In contrast, the multi-insert milled surface showed almost equal or less roughness when burnished by 100 N force compared to 60 N and 80 N.

Furthermore, a consistent trend of decreasing roughness was observed for all measured parameters when comparing the single-insert and multi-insert milled surfaces for the same burnishing force. In addition to these, minimal changes in Sa and Sq values indicate less significant alterations in the topography roughness for all burnishing forces.

Overall, these finding suggest that the choice of milling cutter and burnishing force can have a significant impact on the topography roughness of the surfaces, with potential implications for surface quality and performance in various applications. Further research may be warranted to explore the optimal combination of milling cutter type and burnishing force for achieving desired surface roughness characteristics.

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