

# Development of the surface defect machining method for micro/nano scale material removal processes

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## Abstract

In this paper, a novel method named “surface defect machining” (SDM) which was previously applied to hard turning (HT) processes [1] has been applied to nanometric cutting. Using state-of-the-art tools of molecular dynamics simulation and single point diamond turning (SPDT) experiment, it has been shown that a well controlled SDM process can aid to bridge the gap of turning and polishing processes with respect to attainable machined surface roughness and reduced sub-surface damage.

## 1 Introduction

Improvement in attainable surface roughness from a mechanical micromachining process has been a long sought goal of manufacturing research. Recently, experimental trials were performed on hard steel in conjunction with numerical simulations to propose a novel method named “surface defect machining” (SDM) [1-2]. Based on the outcome of these studies, it was demonstrated that SDM method can aid to improve the machined surface finish merely by generating surface defects on the surface of the workpiece prior to the machining operation. Using molecular dynamics (MD), it is shown in figure 1 that providing surface defects reduces the extent of the sub-surface damage even at nanoscale and hence worth to be explored at nanoscale. This is the motivation of the current work to perform the machining trial.

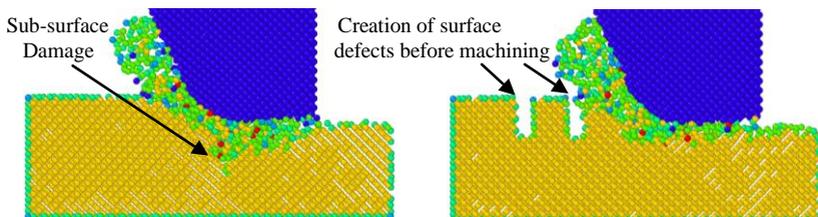


Figure 1: MD simulation of (a) continuum machining (b) surface defect machining

## 2 Experimental setup

Copper specimen of diameter 65 mm was turned on an ultra precision diamond turning machine (Precitech Nanoform 250). The machining parameters used were spindle speed of 587 rpm, feed rate of 2.94 mm/min and uncut chip thickness of 10  $\mu\text{m}$ . The outcome of this trial was than compared with the SDM induced diamond turning. To execute SDM, surface defects were generated on the copper specimen by nanoscratching prior to the SPDT trial (figure 2) for a depth upto 4 micron. The depth of the surface defects was kept less than the uncut chip thickness to avoid any impact load on the cutting tool.

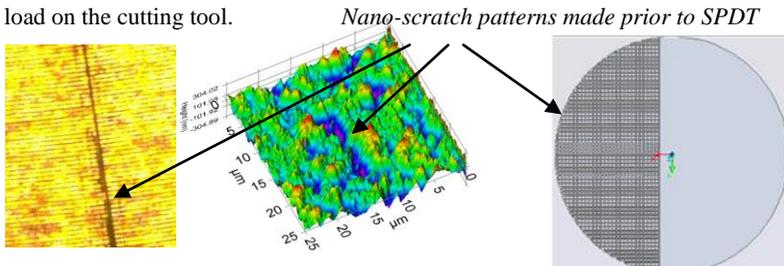
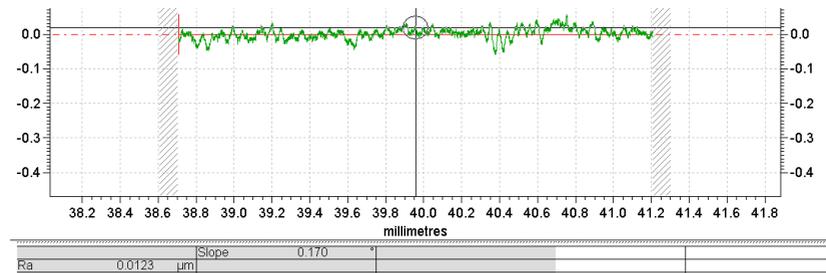
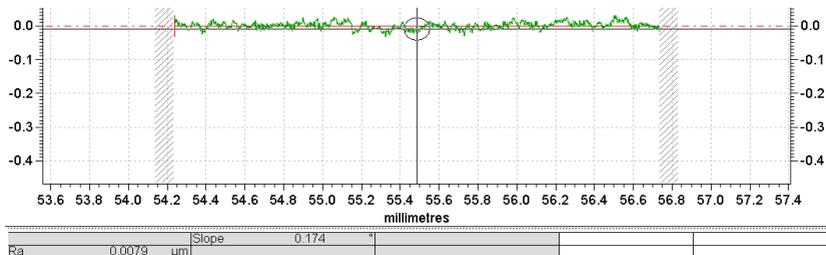


Figure 2: A portion of the scratched copper specimen prior to SPDT

## 3 Results and discussions



(a) Average surface roughness  $R_a = 12.3$  nm obtained through ordinary SPDT



(b) Average surface roughness  $R_a = 7.9$  nm obtained through SDM induced SPDT

Figure 3: Comparison of average surface roughness measured using Form Talysurf

Figure 3 shows the most common tangible outcome of a machining process i.e. average value of the machined surface roughness (Ra). While conventional SPDT provided an Ra value of 12.3 nm, SDM induced SPDT provided the Ra value of 7.9 nm. Few reasons for this improvement are discussed later. In order to characterize component's surface profile into its short, medium and longwave components by their wavelength, the 3D topography of the surface was processed using Gaussian filters followed by a Fourier transformation. This helps to use a measurement technique which not only describes amplitude parameters but also takes into account the spectral distribution of the roughness. Thus, the results shown in figure 4 are basically the measurement of surface roughness in terms of wavelength.

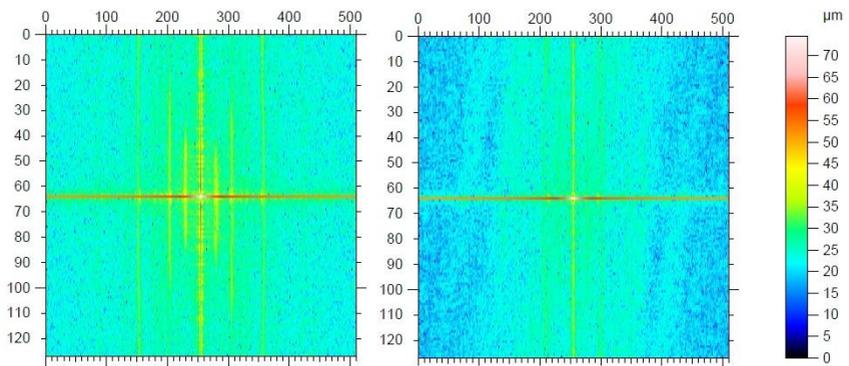


Figure 4: Fast Fourier Transform analysis (a) ordinary SPDT (b) SDM induced SPDT

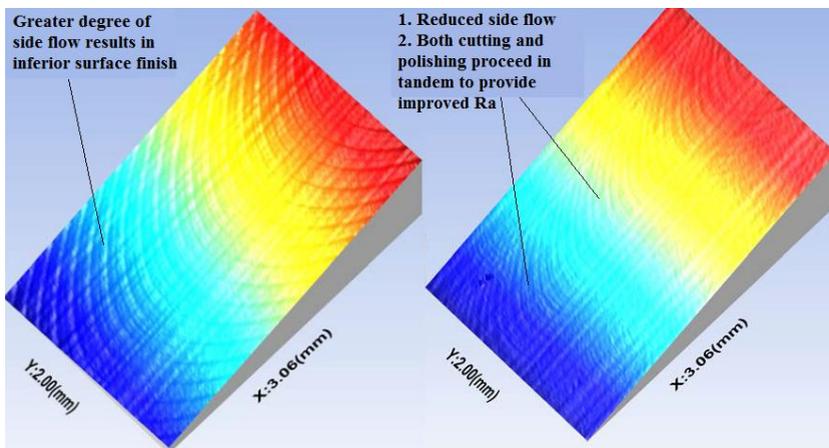


Figure 5: 3D profile of the finish surface (b) ordinary SPDT (c) SDM induced SPDT

From the FFT analysis, the Ra obtained through SDM induced SPDT was found much better compared to the Ra obtained through ordinary SPDT method both in terms of amplitude and spectral density. An important thing however noticeable through the FFT analysis is that the Ra value obtained through ordinary SPDT is more periodic than the induced SDM method. Figure 5 shows the 3D profile of the machined surface under both the machining conditions. A greater degree of side flow is evident during the ordinary SPDT operation in comparison to the SDM induced SPDT method. To gain further insights to this, an MD simulation model was developed [1]. The outcome of the MD simulation result is shown in figure 6.

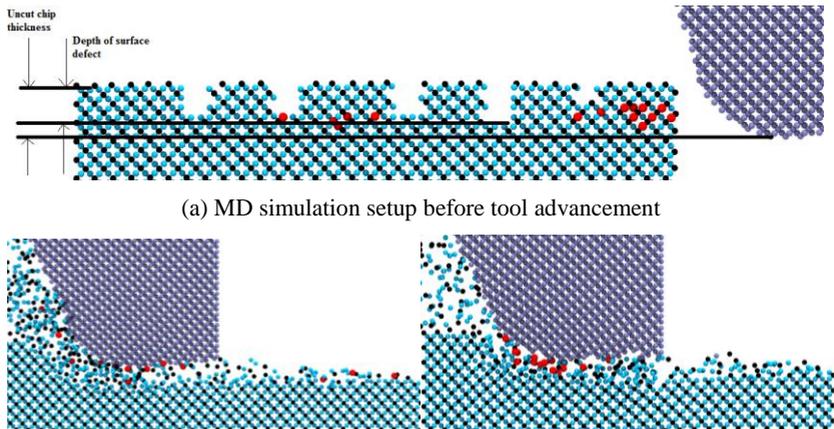


Figure 6: MD Simulation results (b) ordinary SPDT (c) SDM induced SPDT

In figure 6, a few atoms have been coloured red to highlight the differences between the cutting mechanisms associated with the two cases. During SDM, the red coloured atoms continue to travel underneath the cutting tool rather than adhering to the machined surface, suggesting that during machining they rub/polish the machined surface. This deduction is in good agreement with the SDM machined surface roughness shown earlier where feed marks and side flow are greatly reduced when compared to ordinary SPDT. SDM induced SDPT is thus explained to be a potentially superior method of machining over ordinary SPDT.

### References:

- [1] Rashid W.B., Goel S., Luo X., et al., 2013, DOI: 10.1016/j.wear.2013.01.048
- [2] Rashid W.B., Goel S., Luo X., et al., 2013, DOI: 10.1177/0954405412464217