

Enabling ultra high precision on hard steels using surface defect machining

Waleed Bin Rashid¹, Saurav Goel² and Xichun Luo³

¹ *School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH14 4AS, UK*

² *School of Mechanical and Aerospace Engineering, Queen's University Belfast, Belfast BT9 5AH, UK*

³ *Department of Design, Manufacture & Engineering Management, Faculty of Engineering, University of Strathclyde, Glasgow, G1 1XQ, UK*
Xichun.Luo@strath.ac.uk

Keyword: Surface defect machining; hard steel; CBN cutting tool

Abstract

This paper is an extension to an idea coined during the 13th EUSPEN Conference (P6.23) named "surface defect machining" (SDM). The objective of this work was to demonstrate how a conventional CNC turret lathe can be used to obtain ultra high precision machined surface finish on hard steels without recourse to a sophisticated ultra precision machine tool. An AISI 4340 hard steel (69 HRC) workpiece was machined using a CBN cutting tool with and without SDM. Post-machining measurements by a Form Talysurf and a Scanning Electron Microscope (FEI Quanta 3D) revealed that SDM culminates to several key advantages (i) provides better quality of the machined surface integrity and offers (ii) lowering feed rate to 5µm/rev to obtain a machined surface roughness of 30 nm (optical quality).

1. Introduction

It has been a major impediment with single point diamond turning (SPDT) to machine ferrous alloys due to high chemical affinity of iron against carbon and consequent rapid wear of diamond tool. CBN on the other hand, cannot be ground to extremely fine cutting edges like diamond due to its polycrystalline crystal structure. Consequently, it has been a daunting task to machine a steel workpiece to an optical smooth machined surface finish. This research question motivated the development of surface defect machining (SDM) method an idea spined during the 13th EUSPEN conference (P6.23). Although, some level of understanding has been reached by the authors on surface defect machining (SDM)[1-2], some of the underlying

phenomenal reasons of the method are relatively unexplored. This paper unravels a key feature of the SDM method by demonstrating experimentally that SDM method could aid to provide ultra smooth machined surface finish on hard steels merely by using a conventional machine tool.

2. Details of the experiment

A Trumpf (CO₂) laser machine with a peak power of 2.7 kW was firstly used to judiciously create a series of holes on the surface of the workpiece. The workpiece exhibiting such manufactured surface defects was machined on a Mori-Seiki SL-25Y (4-axis) CNC lathe. Two sets of machining trials were performed under the same cutting conditions with the same type of material using a CBN tool (with and without SDM). The feed rate varied from high to low (0.08 mm/rev → 0.005 mm/rev) while the other machining parameters were kept fixed as shown in table 1.

Table 1: Experimental parameters

Number	Details	Values
1	Workpiece Material	AISI 4340 steel hardened up to 69 HRC
2	Diameter of workpiece before turning	28.8 mm
3	Cutting tool specifications (ISO code)	CNMA 12 04 08 S-B
4	Tool nose radius	0.8 mm
5	Tool rake and clearance angles	0° and 5°
6	Feed rate	0.08, 0.03, 0.005 mm/rev
7	Depth of cut	0.2 mm
8	Cutting speed	90 m/min
9	Coolant	None
10	Diameter and depth of holes	0.9 mm and 0.17 mm respectively with 10 mm interspacing between each hole

3. Results and discussion

Figure 1 highlights the variation in the measured surface roughness (average machined surface roughness (Ra) and peak to valley measurement (Rz)) obtained by changing the feed rate during the experiments done by conventional cutting and cutting by using SDM method. It is evident from these plots that the feed rate of 0.02 mm/rev is critical feed rate (because the surface roughness below this feed rate becomes stagnant) for attaining the best possible machined surface roughness on this steel specimen. However, a key finding from these experiments was that the SDM

method enabled providing a better quality of machined surface roughness of about Ra 30 nm for which the corresponding Form Talysurf measurement is shown in figure 2.

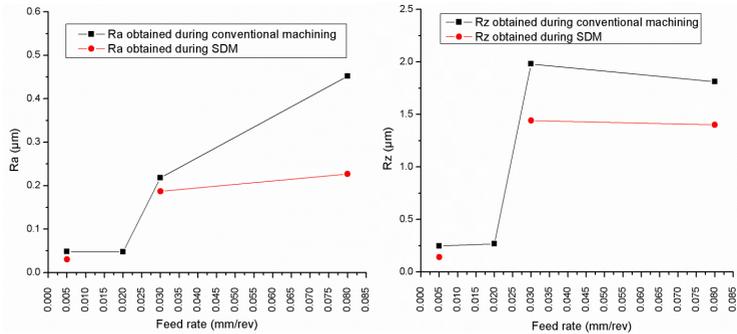


Figure 1: Variation in Ra and Rz with respect to feed rate

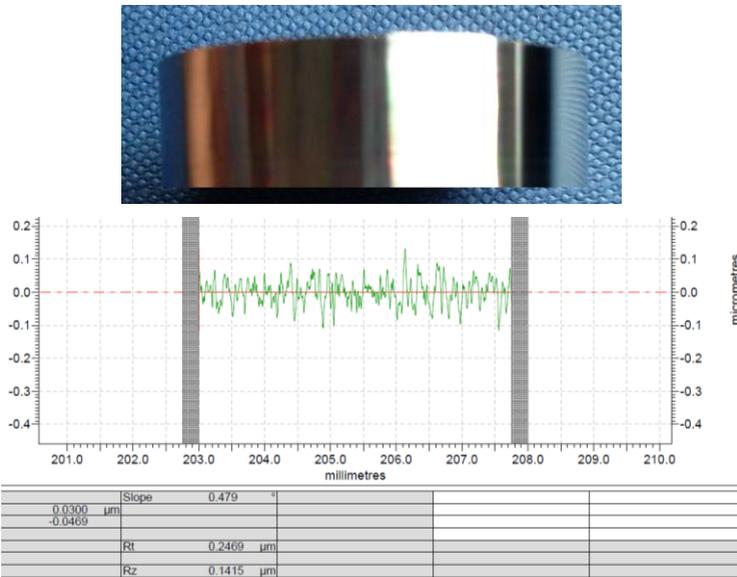
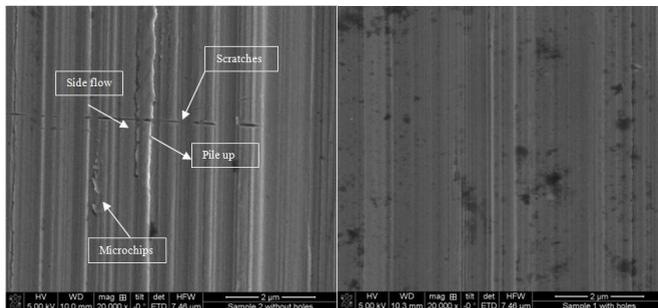


Figure 2: Form Talysurf measurement of the machined surface roughness indicating mirror finish nature of the machined surface of 69 HRC hard AISI 4340 steel workpiece

Figure 2 gives an important indication that the barrier of critical feed rate (as is well recognized during cutting that below a certain critical feed rate ploughing prevails and hence machined surface roughness deteriorates) can be broken by adapting the SDM method and it is possible to obtain a better machined surface roughness *via* the cutting merely by changing the mode of its execution. This could potentially enable

to harness the ultra precision surface finish and suggest that optimisation of the surface defects is another prospective area of study (we will expand on this later).



(a) Conventional HT method

(b) SDM method

Figure 3: SEM examination of the machined surface quality under conditions

Figure 3 shows the scanning electron microscopic examination of the machined surface which was done primarily to highlight the quality of machined surface. Figure 3a is the image of the surface machined using conventional method while figure 3b is the quality of the machined surface obtained using SDM method. Several kind of precursors were observed during conventional machining such as excessive side flow, burrs, weldaments and penetration of these weldaments in the finish machined surface to form scratches on the machined surface. Contrary to this, SDM method showed negligible extent of side flow and no considerable appearance of microchips on the finished surface and was found to be free from such weldaments, the reasons for which are already highlighted earlier[1-2]. SDM could thus pave way to new developments in the manufacturing research especially concerning cutting.

References:

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