

THE EFFECT OF THE CUTTING EDGE ROUGHNESS ON THE SURFACE ROUGHNESS DURING ULTRAPRECISION MACHINING OF HARDENED STEELS

A.G. Mamalis, I. Mészáros¹ and D. Paulmier

¹ Department of Manufacturing Engineering
Budapest University of Technology and Economics
H-1111, Budapest, Hungary

Abstract: The formation of the surface roughness during the machining of hardened steel, similar to the machining of "soft" materials, so far has been considered as a function of the cutting parameters (cutting speed, feed, cutting depth), the minimal chip thickness and the nose radius. Experimental results have not proved the theoretical calculations to be correct, and appeared to have a significant deviation. Actually the surface roughness is depending on the condition and roughness of the cutting edge to a great extent. Theoretical examinations can confirm our experience that a correlation occurs between the cutting edge roughness and the surface roughness. In our exposition we would like to explain our machining experiments, and theoretical examinations, which are meant to complexly expose the relations between the cutting circumstances and the surface roughness.

Keywords: high precision hard cutting, surface topography, atomic force microscope

1 INTRODUCTION

Nowadays ultraprecision hard turning is more and more often used as an alternative of fine grinding. Its advantages particularly prove useful in manufacturing complex profiled surfaces, centric bores. Turning can be carried out effectively and rapidly by moving simple universal tools on the specified tool-path. In case of grinding profiled surfaces, the adequate dressing of the grinding wheel to provide the necessary tool shape, the reconditioning of the wheel during grinding is time consuming and costly process, which requires high level expert knowledge. The attainable dimension accuracy is around 1 μm , the form accuracy is generally under 1 μm . The surface roughness is the same by both machining techniques, R_z is around 0.5 μm , but significantly finer surface finish can be achieved in several cases. However the fast spreading of ultraprecision hard turning is hindered by several factors, among which one of the most important is the dispersion of the roughness values. According to our experimental experiences the surface roughness shows 50% dispersion as well using the same material and machining parameters [1]. The examinations of K.F. Koch [2] in machining hardened steels suggest the same. Further difficulties are resulting from the fact, that in this range of surface roughness pin-testers are not too reliable, while interference methods are difficult to apply. This means that the uncertainty of the measurement can contribute towards significant dispersion of the roughness, but first of all the technological reasons of the dispersion have to be cleared.

2 THE CLASSIC MODEL OF SURFACE ROUGHNESS

Surface roughness is usually examined in the function of cutting parameters. The starting points to determine the theoretical roughness values are the kinematic, geometric relations. Ultraprecision hard turning differs from conventional turning in many respects. While during conventional turning the cutting depth is usually 0.1 ÷ 10 mm and the feed rate is between 0.1 ÷ 1 mm, in case of ultraprecision hard turning generally both the cutting depth and the feed rate are between 1 ÷ 50 μm . This means, that apart from the rare exception, cutting is usually carried out by the cutting edge radius (r_e). Using the theoretical geometric-kinematic relations to calculate the surface roughness in a common machining case ($f = 10 \mu\text{m}$, $a_p = 10 \mu\text{m}$, $r_e = 0.8 \mu\text{m}$) the average roughness will be $R_z = 15 \text{ nm}$ [3]. In practice the surface roughness is larger than this by at least one, but in most cases by two order of magnitude. Whichever model we use that proved well in conventional machining cases, they will

provide dramatic differences from the reality in case of ultraprecision hard turning. A new model has to be developed for ultraprecision hard turning.

3 CUTTING MODEL OF HIGH PRECISION HARD CUTTING

In general cutting tool materials with small CBN content (50%) are suitable for high precision hard cutting. Manufacturers produce their cutting tools with nose radius ($r_e = 0.4 \div 1.2$ mm). Considering the usual values of the depth of cut ($a_p = 1 \div 50$ μm) and the feed rate ($f = 1 \div 20$ μm), it can be stated that in case of high precision hard cutting the machining is done by the nose radius. According to our experiments, within a short pace of time a 1 μm radial dimension loss occurs on the new cutting edge. This loss can be explained clearly if we look at the structure of the cutting edge material. In case of a $r_e = 0.8$ mm average nose radius, the nose radius turns into an approximately 80 μm long nearly straight line, which is parallel to the surface. The geometric relations can be seen in figure 1. In relation to the chip removal mechanisms and the formation of the surface, the cutting edge has to be divided into two parts. The chip removal takes place between points ① and ②, while between points ② and ③ the cutting edge (the worn back face attached to the cutting edge section) is rubbing on the surface. In section B-C, which was taken between points ① and ②, see figure 1., the circumstances of the chip removal are also shown. The conditions of material removal are greatly influenced by the cutting edge radius. Our measurements indicate that the cutting edge radius is $r_\beta = 2 \div 3$ μm . Therefore the model of high precision hard cutting [1] can be applied at this section of the cutting edge (figure 1. section B-C). However the roughness of the machined surface is formed by section ②-③ of the cutting edge. Section ②-③ can not be considered as a geometrically straight line. If we undertake a microscopic examination of the surroundings of the cutting edge we can conclude that the grain size or rather, the structure of the tool material, determine the roughness of the cutting edge. Based on figure 1. a close connection between the roughness of the cutting edge and the roughness of the surface is apparent.

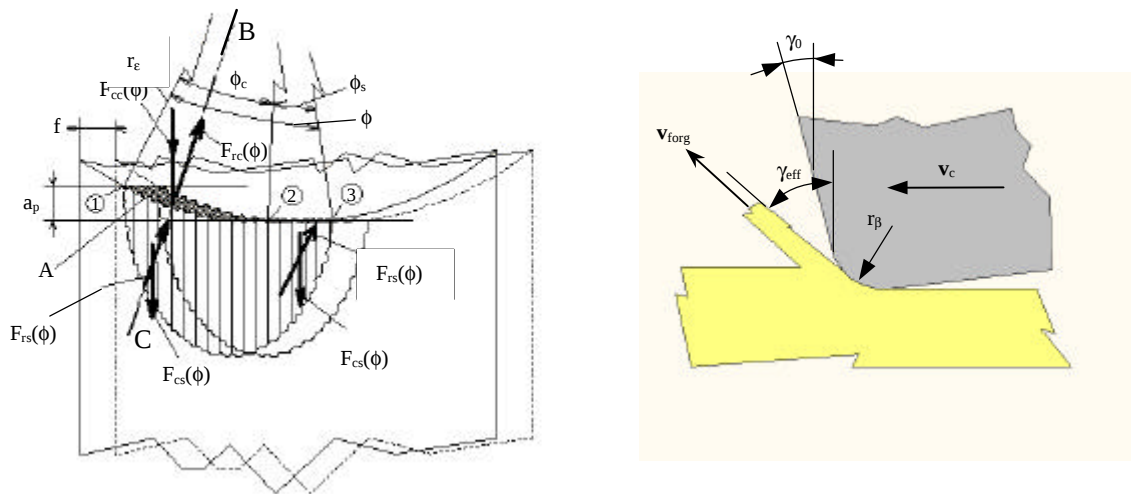


Figure 1. Cutting model of high precision hard cutting

4 SURFACE ROUGHNESS AND SURFACE TOPOGRAPHY

To determine the relations between the surface roughness of the workpiece and the roughness of the cutting tool edge, and to verify the model several experiments have been carried out. On figure 2. the clearance of a half-worn cutting insert can be seen.

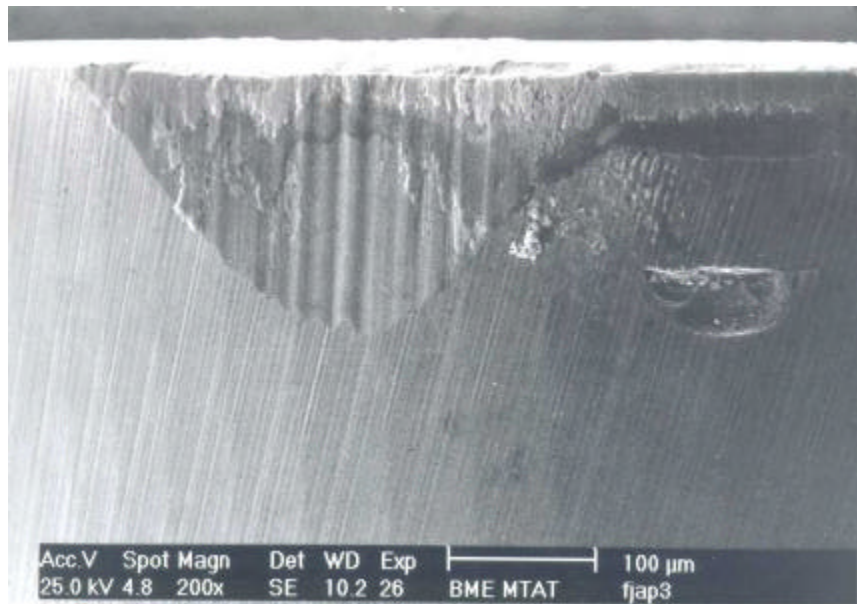


Figure 2. Picture of clearance wear

On the right side of the picture the part where the material removal is done can be well recognised. The worn cutting edge section corresponds to the ②-③ section of figure 1. This section of the tool basically rubs the surface of the workpiece. The roughness of the cutting edge is copied to the surface of the workpiece according to the kinematic conditions.

To be able to verify the model a more detailed examination of the workpiece surface is necessary than the pin-tester allows. However optical surface finish can not be achieved by ultraprecision hard turning, light interference equipment is suitable for the examination (see figure 3.).

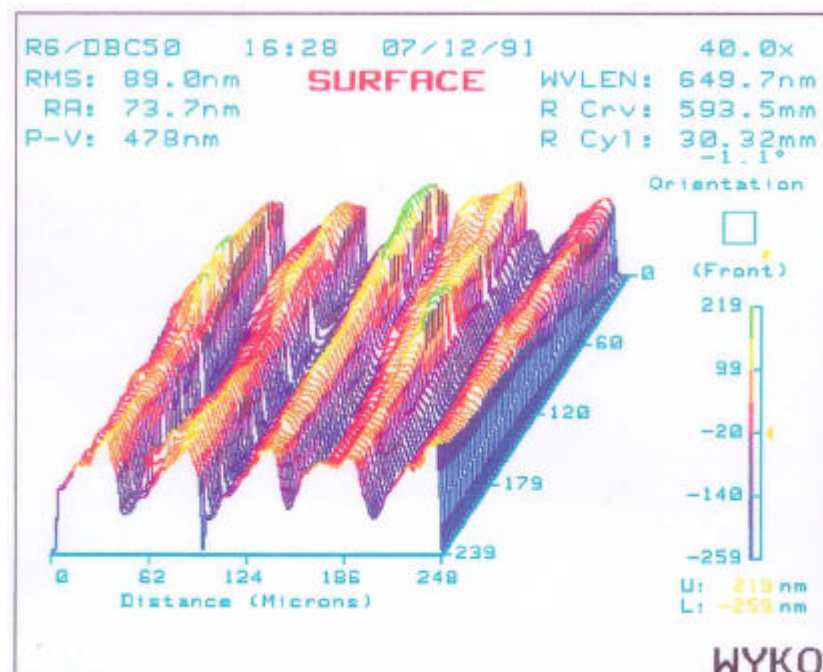


Figure 3. Surface topography of hard turned surface

Figure 4. shows a typical roughness measurement result of the surface using a pin-tester.

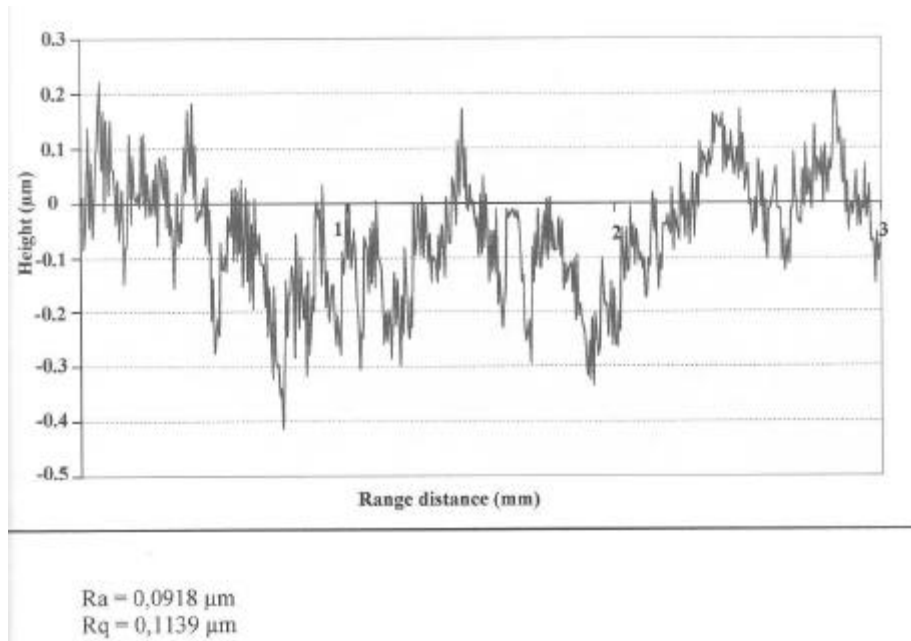


Figure 4. Surface profile of a turned surface

The examination of the surface has been also carried out by an atomic force microscope (AFM). The surface topography can be seen on figure 5.

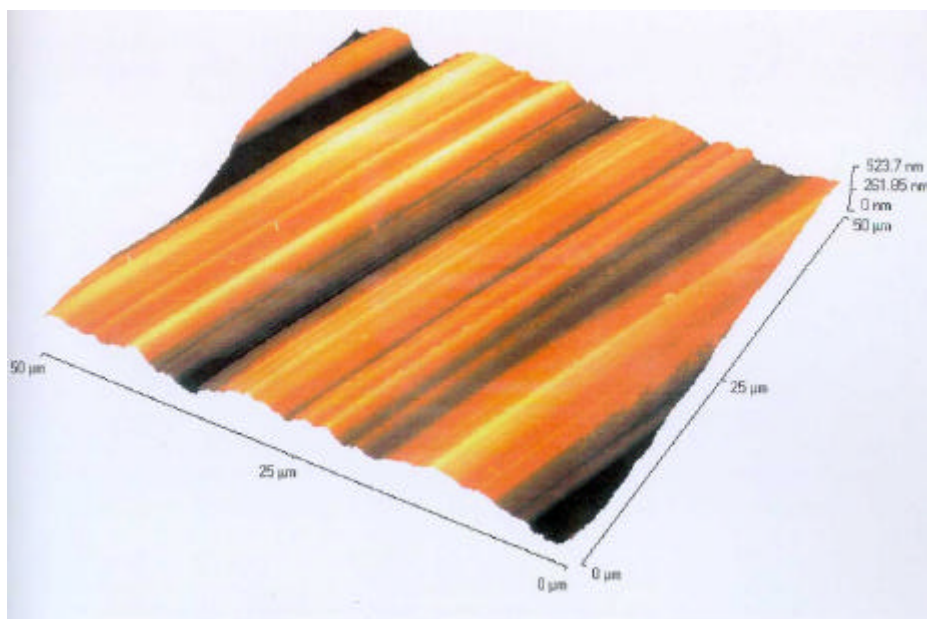


Figure 5. AFM profile of the turned surface

5 SUMMARY

In case of ultraprecision hard turning the formation of the surface roughness can be explained by the cutting edge roughness. According to the conclusions drawn from our experiences, there is a much stronger correlation between the cutting edge roughness and the surface roughness, than between the surface roughness and the machining parameters. More accurate topography of the hard turned surface can be produced by interference surface topography, and AFM.

REFERENCES

- [1] A. Grabchenko, M. Horváth, A.G. Mamalis, I. Mészáros, D. Paulmier, Ultraprecision Machining of Mirror-Surfaces, *OS/N'99*, Krakow, 1999. p. 189-206.
- [2] K.F. Koch, *Technologie des Hochpräzisions-Hartdrehens*, Diss. RWTH Aachen, 1996.
- [3] P.H. Brammertz, Die Entstehung der Oberflächenrauheit beim Feindrehen, *Industrie Anzeiger*, Nr. 2, 6.1. 1961. p. 25-32.

AUTHORS: Prof. A.G. MAMALIS, Manufacturing Technology Division, National Technical University of Athens, Greece, Tel. +30 1 7723688, Fax +30 1 7723689, mamalis@central.ntua.gr
I. MÉSZÁROS, Department of Manufacturing Engineering, Budapest University of Technology and Economics, Tel. +36 1 4632517, Fax + 36 1 4633176, imesaros@manuf.bme.hu
D. PAULMIER, Laboratoire de Physique et de Mécanique des Matériaux (ERMES)
Institut National Polytechnique de Lorraine, France, Tel. +333 8359 5616 Fax +333 8359 5617,
Daniel.Paulmier@ensem.u-nancy.fr