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Roughness measurements according to existing standards with a metrology AFM profiler

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Abstract:

Conventional surface profilers used for roughness measurements can scratch soft surfaces. By means of an atomic force microscope (AFM) we found scratches on smooth surfaces of gold, aluminium, copper, bronze and steel. To obtain comparable roughness measurements it is important, that, besides the roughness parameters, also the transfer function for the measurement process is normalised. For this purpose roughness standards define the shape of the probe and the transition bandwidth given by two gaussian filters. To apply the filters correctly a minimum scan length of about 160 µm is required. With our metrology AFM profiler it is possible to measure profiles with length of up to 380 µm. The profiles reveal all the fine details of the surface and allow then step by step to study the influence of the profiler tip shape and the filtering process.

Introduction

Roughness is in many cases related to friction and wear. These surfaces are then made of hard materials and therefore roughness measurements with traditional diamond stylus profilers are adequate. However, roughness can also be interesting in relation with gas absorption, corrosion or optical surface quality. Here the smooth surfaces consist often of soft materials such as pure metals (aluminium, gold, copper, etc.) or polymers and lacquers. For roughness measurements on such surfaces diamond stylus profilers can not be used because they will scratch the surface and the measured value will be meaningless. Optical non-contact methods have a limited lateral resolution and no standardised procedures are available for them. With AFMs the interaction force between the probing tip and the sample is very small and the spatial resolution is high. Unfortunately, typical instruments have measurement ranges which are too short to apply the existing standards for roughness.

In this paper we report on surface damages caused by diamond surface profiling on various metals and introduce roughness measurements made by a long range AFM profiler according to existing standards. The effect of tip shapes and filtering is analysed.

Experimental setup

The AFM profiler system used consists of a commercial metrology AFM head and a linear sample displacement stage. The AFM head has a parallelogram type scanner with capacitive position sensors. Below this metrology AFM head there is a sample displacement stage with monolithic flexures forming a double parallelogram. This piezo actuated stage provides a highly linear motion over 380 µm. Its displacement is simultaneously measured by a capacitive position sensor and a differential plane mirror interferometer of the Jamin type.

Details about this system and about accurate pitch, step height, CD and particle diameter measurements were published earlier [1-4]. In contrast to classical diamond profiling with probing forces in the mN range the AFM technique works with forces in the nN range. For all measurements presented here the dynamic force mode was used which minimises the lateral forces on the tip.

Diamond profiler measurements

A conventional surface profiler for roughness measurements [5] was tested on various polished metal surfaces. A diamond tip with 90° cone angle and 2 µm tip radius was used with a load of (0.5 ± 0.1) mN. Such values are given in EN ISO 3274, a standard about instrument characteristics for roughness measurements.

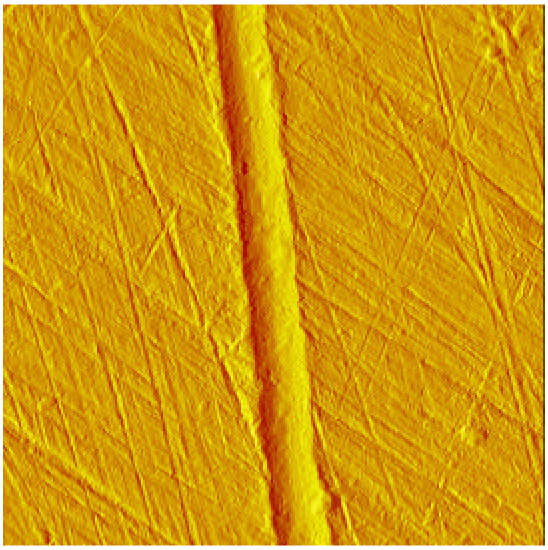

figure 1: AFM image of gold surface after profiling. Image 10 µm x 10 µm.

Using the AFM we found scratches from profiler measurements on gold, which is of course very soft (Fig. 1). But also on aluminium, copper, bronze and even on steel we found scratches. Only for hardened steel, a gauge block, no scratch was found. The fine features of the surface were destroyed by the diamond tip and a new surface was created at the bottom of the scratch whose roughness was independent of the original surface. Only for surfaces with a roughness much larger than the scratch depth a correlation is found again.

The AFM was used to quantify the scratch depths. Figure 2 shows depths of 5 nm to 60 nm measured on various materials. The harder the material the smaller the depths.

According to Hertz theory as described by Vliet and Schellekens [7] damages would already be expected at much lower forces. On steel the maximum allowed force on a 2 µm tip would be 2.5 µN and on aluminium only 0.4 µN. In our case the load for steel was 200 times higher. The standard EN ISO 3274 requires even a higher nominal force on the profiler tip of 0.75 mN.

The situation is even worse with respect to dynamic forces that act between tip and surface when the tip is stopped on the surface after the initial approach. The higher the approach speed and the inertia of the stylus, the higher the dynamic forces. With the used approach speed of approximately 0.5 mm/s we found even pits on hardened steel, i.e. a gauge block with a hardness of approx. 64 HRC. These pits had a depth of 50 nm, whereas on steel (St37) the depth was 120 nm.

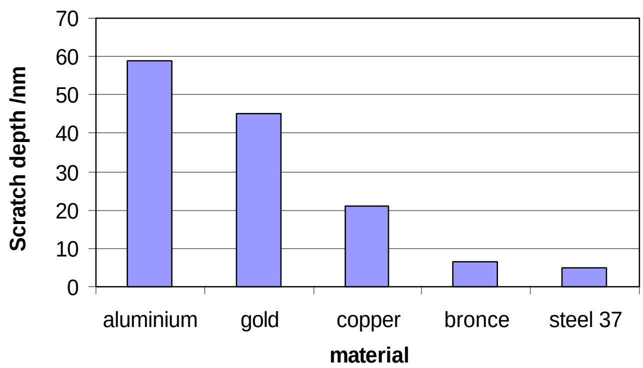

figure 2: Scratch depths measured with the AFM on various materials.

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AFM roughness measurements

AFMs use very small probing forces in the nN range. This allows measurements on soft surfaces without any damage.

To obtain comparable roughness measurements it is important, that, besides the definition of the roughness parameter (EN ISO 4287), also the transfer function for the measurement process is normalised. For this purpose the standards define the shape of the probe (EN ISO 3274) and the transition bandwidth (EN ISO 4288) given by two gaussian filters λs and λc (EN ISO 11562). Unfortunately, conventional AFMs have lateral measurement ranges that are too small to apply the existing standards for roughness. The smallest evaluation length proposed by the EN ISO 4288 standard is 80 µm and therefore a minimum scan length of about 160 µm is required to apply correct filtering. With our metrology AFM profiler it is possible to measure profiles with length of up to 380 µm. The profiles reveal all the fine details of the surface and allow then step by step to study the influence of the profiler tip shape and the filtering process. The profiles were typically acquired over 200 µm with a data spacing of 0.05 µm (4'000 data points).

The roughness value determination out of a raw profile involves several process steps. First, the profile is transformed in a way that corresponds to the effect of probing the surface with a normalised conical tip with a radius of 2 µm and a cone angle of 90° (tip deconvolution), followed by a shape fit which is usually a LS line fit. Second, the profile is low pass filtered to remove the high frequency features by applying a gaussian filter with λs = 2.5 µm. This filter should reduce the effect of tip shape variations. Third, the profile is high pass filtered to remove the low frequency features, called waviness, by applying a gaussian filter with λc = 80 µm. The gaussian weight function needs data on both sides of a point were it is applied. Therefore a raw profile range is needed which is at least by one λc larger than the final evaluation length.

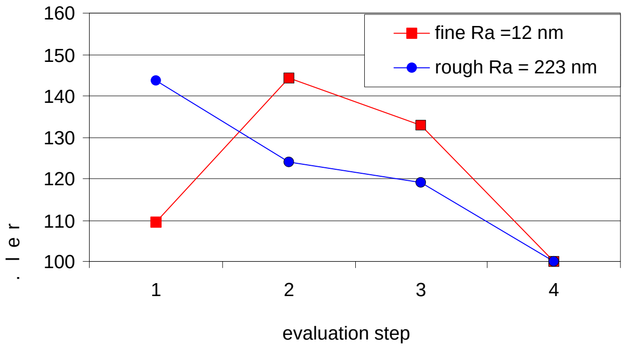

figure 3: Effect of profile process steps on the finally calculated Ra value. 1. Raw data, 2. Tip deconvolution, 3. λs-filter and 4. λc-filter.

Each step has a considerable influence on the final roughness value (Fig. 3). The influence depends also largely on the surface character. Two different types of surfaces were taken as examples, a smooth and a rough surface. In general the roughness value is reduced by the filtering. The tip deconvolution, however, can have an effect in both directions.

The tip shape, mainly the radius, has a strong effect on the roughness values. After low pass filtering with λs = 2.5 µm one would not expect a large influence for radii below 2 µm. This was tested on the two profiles which have different surface characters. The first profile was from a ground steel surface with an Ra value of 223 nm. Ra decreased with increasing tip radius, as expected. A variation of the radius from 1 µm to 3 µm resulted in a change from +10% to -5% with respect to the Ra value at the nominal radius of 2 µm. The second profile was from a polished steel surface with an Ra value of 12 nm. Unexpectedly, here, the value increased with increasing tip radius. A variation of the radius from 1 µm to 3 µm resulted in a Ra value change from -15% to +10% with respect to the Ra value at the nominal radius of 2 µm (Fig. 4).

By looking at this profile in detail the reason for this effect can be seen. The surface is mainly flat but there are small sharp bumps on it probably due to polishing grains which got stuck in the soft surface (Fig. 5). These bumps probe rather the tip than vice versa. Therefore the bumps seem to be broader when probed with a larger tip. As the rest of the surface is mainly flat this leads, even after further filtering, to higher Ra values.

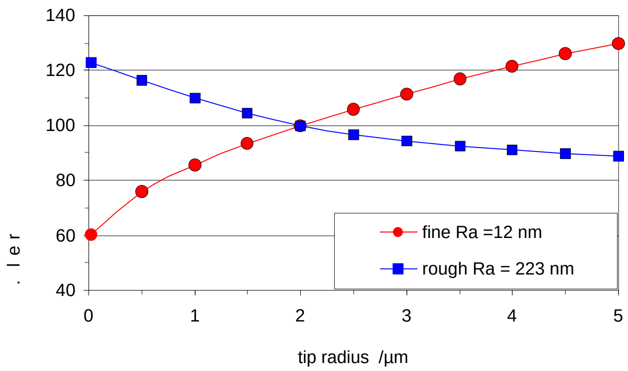

figure 4: Effect of tip radius on the final Ra value for two different roughness profiles.

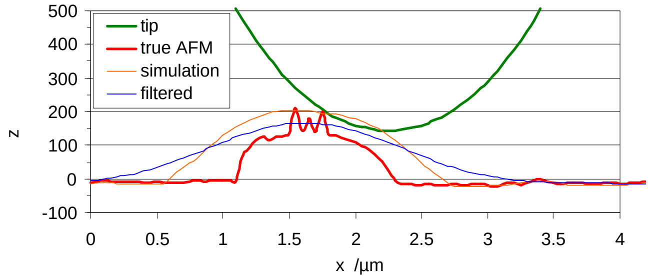

figure 5: Detail of the smooth surface. A small sharp bump is probed larger with a larger tip. This leads after further filtering to higher Ra values.

Conclusion

Conventional surface profilers used for roughness measurements can scratch soft surfaces and lead then to incorrect measurements. The tip load required by the standard EN ISO 3274 is much too high for many technically interesting materials.

With our AFM profiler measurements on soft surfaces can be done without any damage. The profiles with length of up to 380 µm can be processed in accordance with existing standards for roughness. As almost “true” surface profiles are measured by the AFM, the influence of the profiler tip shape can be studied. For reasonable tip variations the influence on the Ra value is in the order of ±10%. For other roughness parameters like Rp, Rv or Rz this influence can be even larger.

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