An objective method to measure and evaluate the quality of sanded wood surfaces

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Abstract

No agreed guidelines exist in wood surface metrology about how to objectively measure and evaluate the surface quality and existing general standard methods and corresponding software are not usually applicable to wood. This paper presents a review of a method developed for sanded wood surfaces, which covers the choice of instrument type, the measuring resolution, the minimum evaluation length, aspects of filtering and the separation of processing roughness from anatomical irregularities. Compared with previous studies in the literature, processing roughness parameters calculated in this study excluded the influence of wood anatomy and represent objective references for the quality of sanding.The method was tested on several sanding variables, but was used in this paper to evaluate the influence of grit size on the quality of European oak (*Quercus robur* L.) sanded with P120, P150, P180, P240 and P1000. Grit size measured with the method above had a clear influence on surface roughness, the finer were the grits the smoother was the surface. Roughness values were fairly close together with P120, P150 and P180 and much smaller with P240 and P1000. This indicates that for oak it is not economical to have a sequence of sanding operations in the domain of fine grit sizes. The method can further be used to evaluate roughness parameters for different combinations of sanding variables to optimise the sanding process.

1 Introduction

The quality of sanding determines the final quality of a finished wood surface and influences the finishing costs. The principal measure of the quality of sanding is the surface roughness, so a greater understanding of the effect of process parameters on surface roughness would encourage the optimisation of sanding operations. Although methods for measuring surface roughness have been standardised for homogenous materials, they are not applicable to wood, and no other specific guidelines have been developed (Krish & Csiha 1999).

Roughness represents the finer irregularities of the surface texture that are inherent in a machining process (ASME B46.1 1995). However, profile data from any nominally flat surface contains not only roughness, but also form errors and waviness that do not characterise the processing. Form errors and waviness should be excluded from any assessment of the surface roughness. Form errors constitute large deviations from the nominal shape of the workpiece. They may be due to internal stresses in the wood or inaccuracies in the machine- tool- workpiece system.

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Form errors are removed by a least-squares regression to obtain the primary profile (ISO 3274 1996).

Waviness is caused by incidental variables such as machining vibration or differential shrinkage within the growth ring. Waviness is removed by numerical filtering of the primary profile. Filters are categorised by their wavelength cut-off value λ, which separates the wavelengths that are within the range of interest for a particular feature from those that are not (ISO 11562 1996). The line corresponding to the wavelength suppressed by the profile filter is called the mean line.

Filtering wood surface data is complex because wood contains a specific anatomical structure that creates a surface texture independent of any processing. When this anatomical roughness is greater than the roughness due to processing, it creates distortions when processing data with filters from current general standards. Standard profile filters in ISO 11562 and ISO 13565-1 introduce a type of distortion known as “push-up” (Krish and Csiha, 1999), especially in areas with grouped pores (Gurau *et al*. 2005), as well as end effects in the first and last half cut-off lengths of the profile (Figure 1). The distorted profile may be compared with a profile with no distortion (Figure 2).

Irrespective of the distortion, anatomical irregularities can obscure the pattern of the processing roughness, particularly where a fine grit size has been used. A proper evaluation of the quality of sanding implies that anatomical irregularities are excluded from the roughness data (Westkämper & Riegel 1993).

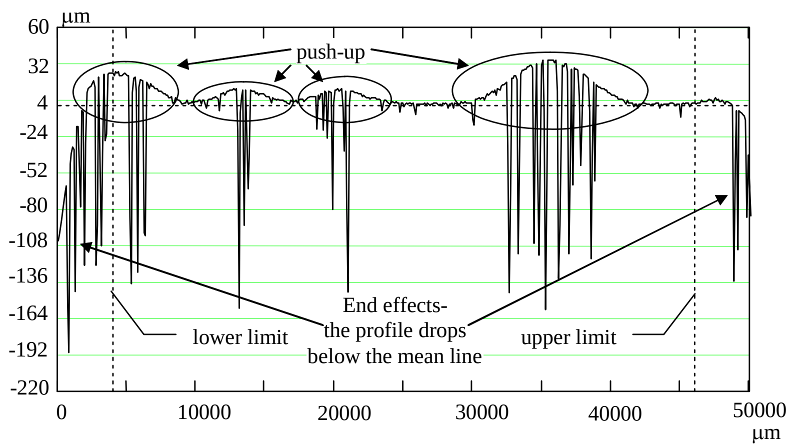

Figure 1: Roughness profile with “push-up” distortions and “end effects” introduced by the Gaussian filter in ISO 11652 1996, from oak sanded with P 1000. Vertical dashed lines mark the levels of the first and last half cut-off length of the filter.

This separation leads to the processing roughness profile. Roughness parameters can be calculated from processing roughness profiles that allow comparisons to be made between different surfaces. If these parameters are to be useful, they must be repeatable, which implies some standardisation of factors affecting their measurement and calculation. Such factors include the measuring instruments, measuring and filtering methods and the choice of standard or non-standard parameters.

A detailed set of recommendations for accurately measuring and evaluating the processing roughness of sanded wood surfaces was developed by Gurau (2004). This paper contains a review of the proposed method and the effect on sanding roughness of varying the grit size.

2 Methodology

The method described here addresses the choice of measuring instrument, the correct measuring direction, resolution and evaluation length. For data evaluation, the method describes ways of obtaining profiles free of distortions, and separating the processing roughness from anatomical irregularities.

2.1 Measurement variables

2.1.1 The choice of instrument type

Taylor Hobson instrument, TALYSCAN 150, was used that could apply two of the most common measuring techniques, laser triangulation and stylus scanning, with a single handling of the specimen. Since only the scanning head was changed, this instrument offered the advantage of inspecting exactly the same area with both methods. Their suitability for wood surfaces was evaluated in terms of their repeatability and their ability to detect peaks and valleys.

The stylus was better able to detect surface irregularities than the laser triangulation device, and was more accurate and repeatable (Gurau 2004). Those characteristics made the stylus more reliable in meeting the objectives of this research in that it was better able to separate processing and anatomical irregularities. However, the stylus was significantly slower than the laser triangulation, and so was possibly less suitable for in-line quality control.

2.1.2 The choice of measuring direction

The influence of measuring direction was examined on roughness parameters calculated from an oak surface sanded along the grain with P60 grit. The surface was measured with sequential scans across the sanding marks, but the roughness parameters were evaluated both along and across the sanding marks.

Wood surfaces should be measured in the direction that gives the maximum values of the irregularities. Parameters across the grain were higher and had lower standard deviations than those along the grain. The variation among profiles along the grain is due to the variable depth of the anatomical features and of the grit marks. A measuring direction across the sanding marks was more meaningful, and it was also suitable for further separation of sanding marks from wood anatomy.

2.1.3 The choice of measuring resolution

A high resolution provides a very detailed data set that can be filtered later, but the time for scanning and data processing is significantly higher than for a low resolution. The best resolution is the lowest resolution that still allows an accurate evaluation of roughness parameters.

The effect of varying the resolution was investigated on beech and spruce specimens sanded with P1000 grit size and oak specimens sanded with P1000 and P120 grit size, scanned at 1 μm resolution. It was assumed this resolution captured all the anatomical and processing details, subject to limitations given by the geometry of the stylus and the precision of the instrument. Lower resolutions of 2, 5, 10, 20, 50 and 100 μm were obtained as sub-sets of the original data. Since the datasets were from the same surfaces and differed only in their resolution, the effect on the roughness parameters of choosing different resolutions could be clearly observed. For resolutions lower than 1 μm the error for each parameter was calculated in percentage terms.

It was found that although the resolution was sensitive to the grit size, a value of 5 μm was reliable enough to be recommended for measuring wood surfaces sanded with commercial grit sizes.

2.1.4 The choice of evaluation length.

The reliability of the evaluation of any roughness parameters depends on the length of the profile that is evaluated. A long evaluation length increases the reliability of the roughness parameters (ISO 4288 1996) since it increases the probability of recording a profile that contains the variation of the surface. The maximum evaluation length depends on the capacity of the measuring instrument. The sensitivity of the roughness parameters *Ra*, *Rk* and *RSm* from ISO 4287(1998) and ISO 13562-2 (1996) to the evaluation length was investigated on profiles from tangential surfaces of oak and spruce sanded with P120 grit. The roughness parameters were initially calculated over a 5 mm length, taken as the first 5 mm of the profile. The evaluation length was gradually increased to 50 mm. It was found that wood does not comply with the evaluation length requirements of the general standard ISO 4288 (1996) because of its variable anatomy. An evaluation length of 50 mm was most suitable for wood, because the amount of variation of the roughness parameters stabilised.

2.2 Wood surface evaluation

2.2.1 Form error removal

According to ISO 3274 (1996), form errors can be removed by fitting a polynomial regression through the original data. The primary profile is obtained by subtracting the regression function from the original data. For wood surfaces it was found that the regression was adversely affected by the presence of deep pores under a smoother plateau, and particularly by grouped pores. However, when the primary profile was used only to obtain the roughness profile, the standard method in ISO 3274 (1996) introduced only negligible distortions in the roughness profiles. An algorithm was proposed for the automatic selection of the function with best fit based on comparing R^2 values for different polynomial regressions.

2.2.2 Filtering the primary profile

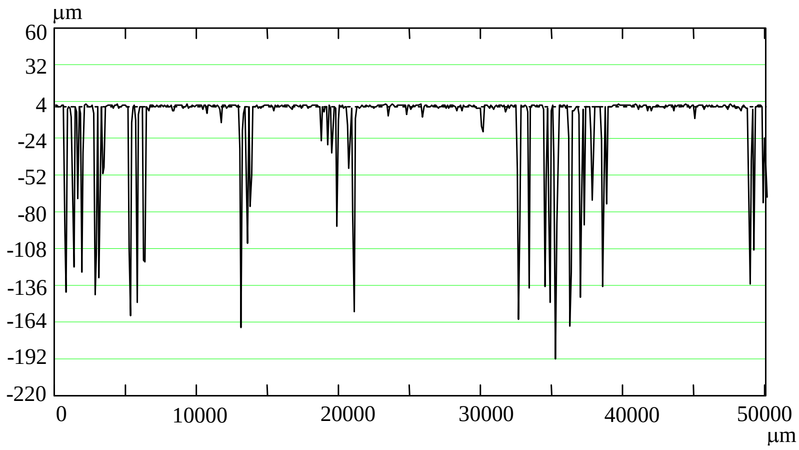

Figure 2: Roughness profile with no distortions, oak sanded with P1000.

The "push-up" and end effects produced by ISO 11562 (1996) and ISO 13565-1 (1996) can be fully corrected, as Figure 2 shows when compared with Figure 1.

A number of profile filters were examined and the one that introduced the least distortion was the Robust Gaussian Regression Filter (RGRF), described in a standard in preparation, ISO/DTS 16610-31 (2002). It is a modification of the Gaussian filter from ISO 11562 (1996) and is applied iteratively to a data set until a convergence condition is met.

2.2.3 Separating the processing roughness from the wood anatomy

The Abbot curve is a material ratio curve defined in ISO 13565-2 (1996). It is a straightforward tool for calculating the real distribution of the profile heights from a distortion-free roughness profile.

In Figure 3, the Abbot curve is constructed by sorting the profile data in descending order. Statistically outlying peaks and valleys appear as non-linear regions in the Abbot-curve, and can be excluded. The upper and lower points of abrupt change in the local curvature of the Abbot-curve were identified by monitoring the variation of its second derivatives (Figure 3). These points were taken to mark the thresholds for the core data (Figure 4).

Processing roughness was defined as the core roughness of a profile where the outlying peaks and valleys have been replaced with zeros. The anatomical roughness was taken as the valleys below the lower threshold, while the peaks above the upper threshold represent the fuzziness.

Fuzziness is caused by groups of fibres that are attached to the surface at only one end; it varies with species, density and moisture content and to a lesser extent with processing.

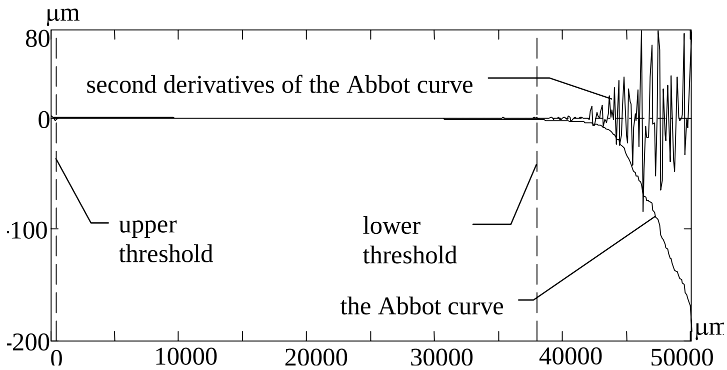

Figure 3: Detection of the lower and upper thresholds in the Abbot curve, oak sanded with P1000.

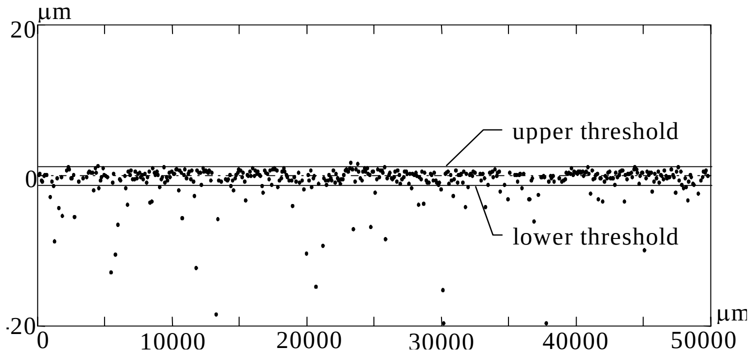

Figure 4: Separation of the core roughness profile from wood anatomy, oak sanded with P1000.

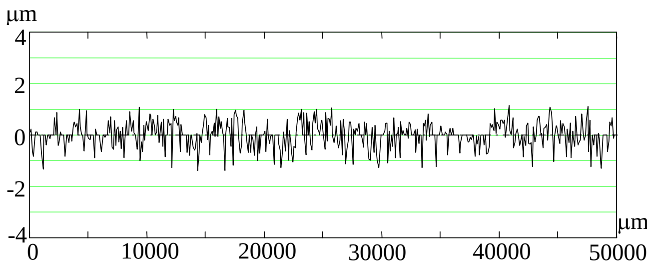

Figure 5: Processing roughness of an oak profile sanded with P1000.

Figure 5 shows the processing roughness of an oak profile sanded with P1000, after the separation. Note the small range on the y-axis for this fine grit size.

2.2.4 Calculation of processing roughness parameters

The general standards ISO 4287 (1998) and ISO 13565-2 (1996) give a variety of quantitative measures of surface roughness. A single value of these parameters is defined on a nominal interval called the sampling length. The length used for assessing the profile is called the evaluation length, which in general should contain five sampling lengths. However, given the variability in wood anatomy, roughness parameters calculated over the evaluation length were more reliable than those defined on sampling lengths, and therefore are recommended for a wood surface.

Among roughness parameters, *Rk*, which is the core depth roughness defined in ISO 13565-2 (1996), seemed to be the most useful indicator of the processing roughness.

3 Experimental method

The sensitivity of the method of separating the processing from anatomy was tested on European oak surfaces (*Quercus robur* L.) sanded with various grit sizes. Oak is a species that contains deep pores below the sanded surface, which must be removed from the profile. Oak was sanded with grit sizes ranging from P120, P150, and P180, as they are common commercial values for the final sanding before coating. Recent finishing techniques require even finer grit sizes from P220 to P280, a value of P240 was tested as an example of such fine commercial sanding. P1000 is too fine for commercial applications, but it was included for the sake of comparison and to test the sensitivity of the separation algorithm to the grit size.

The specimens were conditioned to a stable moisture content of approximately 12 % by storage in a climate controlled environment. Two replicates were prepared from different boards. The specimens were pre sanded parallel to the grain in a wide belt sander, firstly with a P60 grit size followed by P80, to remove the irregularities from sawing and planing operations. Then the specimens were cut to surface dimensions of 100 mm x 90 mm, suitable for the final sanding.

The final sanding was performed on a Makita 9402 portable belt sander. The machine was inverted and mounted on a solid base, and a stiff frame was constructed around the equipment. The specimen was held rigidly at all times on top of the belt. The sanding was performed with aluminium oxide closed-coated cloth belts measuring 600 x 100 mm. The processing was conducted at a constant contact pressure of 0.0032 N/mm^2 and a belt speed of 5 m/s, the fastest speed on this machine.

Before the specimens were sanded, the new sanding belts were dulled by continuous sanding for 30 minutes, to remove the initial sharpness of the abrasive grits. Fresh belts result in high roughness values that are not representative of the process.

The surface measurements were carried out on the TALYSCAN 150. The scanning head was a stylus with 2.5 μm tip radius and 90° tip angle, which moved across the surface perpendicular to the sanding marks at a speed of 1000 μm/s.

To analyse the influence of grit size, six areas of 2.5 mm x 50 mm were randomly selected from the surfaces of the two specimen replicates. Each area contained 5 profiles scanned on a length of 50 mm, which made a total of 30 profiles for a specific sanding variable investigated. Each profile was recorded at a resolution of 5 μm, while the gap between profiles was 500 μm.

Data was stored in ASCII format and processed with algorithms written in MathCad™. Form errors were removed with a 2nd order polynomial regression, which proved to be the best fit of the initial data.

The roughness profiles were obtained by filtering the surface with the Robust Gaussian Regression Filter with a cut-off length of 2.5 mm, which produced undistorted profiles.

The processing roughness was separated from the other irregularities of the surface as described above. Peaks and valleys that were not part of the processing roughness were replaced with zeros, which were excluded in the calculation of roughness parameters.

The processing roughness was evaluated with various roughness parameters, but *Ra* and *Rq* from ISO 4287 (1998), and *Rk*, *Rpk* and *Rvk* from ISO 13565-2 (1996) were included in this paper.

4 Results and discussion

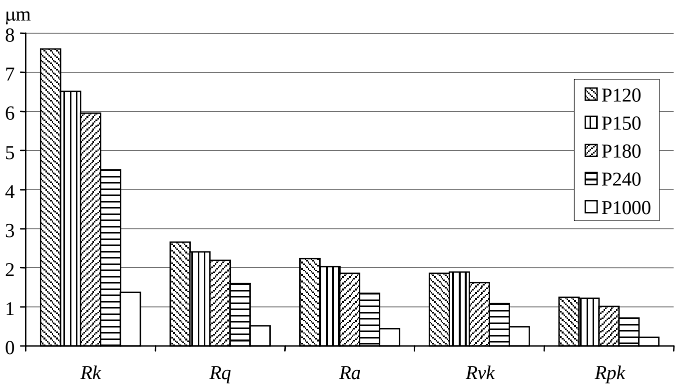

Figure 6: The influence of grit size on roughness parameters *Rq*, *Ra*, *Rk*, *Rvk* and *Rpk* on oak surfaces.

The results shown in Figure 6 demonstrate that all the roughness parameters were sensitive to grit size. Their values were fairly close together with P120, P150 and P180 and much smaller with P240 and P1000.

Normally sanding is performed in a sequence of grit sizes from coarse to fine. Close roughness values obtained for the commercial grit sizes P120, P150 and P180, which are normally used in final sanding operations, indicate that for oak it is not economical to have a sequence of sanding within the fine grit sizes.

5 Conclusions

A set of recommendations for wood surface metrology developed by Gurau (2004) was tested on European oak surfaces (*Quercus robur* L.) sanded with various grit sizes. Compared with previous studies in the literature, processing parameters calculated in this study excluded the influence of wood anatomy and represent objective references for the quality of sanding. All the roughness parameters were sensitive to the sanding variables tested; the finer were the grits the smoother was the surface

However, sanding with finishing grit sizes P120, P150 and P180 produced very close roughness values for oak. This indicates that for oak it is not economical to have a sequence of sanding operations in the domain of fine grit sizes.

The method can further be used to evaluate roughness parameters for different combinations of sanding variables to optimise the sanding process.

References

ASME B46.1. (1995) “Surface Texture. (Surface Roughness, Waviness, Lay)”.

Gurau, L., Mansfield-Williams, H. & Irle, M. (2005) “Processing Roughness of Sanded Wood Surfaces”. Holz als Roh- und Werkstoff. 63(1), pp.43-52.

Gurau, L. (2004) “The Roughness of Sanded Wood Surfaces”. Doctoral thesis. Forest Products Research Centre. Buckinghamshire Chilterns University College. Brunel University.

ISO 11562 (1996) “Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Metrological Characteristics of Phase Correct Filters”.

ISO 13565-1 (1996) “Geometrical Product Specifications (GPS) – Surface Texture. Profile Method. Surfaces Having Stratified Functional Properties. Part 1: Filtering and General Measurement Conditions”.

ISO 13565-2 (1996) “Geometrical Product Specifications (GPS) – Surface Texture: Profile Method; Surfaces Having Stratified Functional Properties – Part 2: Height Characterisation Using the Linear Material Ratio Curve”.

ISO 13565–3 (2000) “Geometrical product specification (GPS). – Profile method. Surfaces having stratified functional properties”.

ISO 3274 (1996) “Geometrical Product Specifications (GPS) – Surface Texture. Profile Method –Nominal characteristics of contact (stylus) instruments”.

ISO 4287 (1998) “Geometrical Product Specifications (GPS). Surface Texture. Profile Method. Terms. Definitions and Surface Texture Parameters”.

ISO 4288 (1996) “Geometrical Product Specifications (GPS) – Surface Texture. Profile Method – Rules and Procedures for the Assessment of Surface Texture”.

ISO/DTS 16610-31 (2002(E)) “Geometrical product specification (GPS) – Filtration. Part 31: Robust profile filters. Gaussian regression filters”. In Draft.

Krish, J. & Csiha, C. (1999) “Analysing Wood Surface Roughness Using an S3P Perthometer and Computer Based Data Processing”. In:Proc. XIII Sesja Naukowa “Badania dla Meblarstwa”. Poland. pp.145-154

Westkämper, E. & Riegel, A. (1993) „Qualitätskriterien fur Geschlieffene Massivholzoberflächen“. Holz als Roh- und Werkstoff. 51(2), pp.121-125.