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DOCTORAL (Ph.D) THESIS

STUDY OF WOOD SURFACE ROUGHNESS ON P AND R PROFILE FOCUSED ON BIG POROUS SPECIES

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I. The object and aim of the research

When analyzing surface roughness of different wood species there appears a special problem – deriving from the nature of the material – that until some species have an even anatomical structure, free of big opened vessels, till than other species have “bigger-smaller” crosscut vessels. The presence and number of big pores has a serious influence on results by distortion of roughness parameters, makes impossible the adjudication of machining quality. In course of surface roughness evaluation for big porous species there is the problem that even in case of a machining quality supposed to be good the different roughness parameters obtained as result of various statistical evaluations suggest a bad machining quality. This fact raises the necessity that for an objective adjudication of machining quality the vessel grooves to be filtered out. The problem is characteristic for measurement and evaluation of big porous species where crosscut vessels appear along the measuring length (acacia, oak, ash, birch). Because this phenomenon affects only a group of species fell out for long time from the focus of attention for a long time. With raising quality expectations there is a need for changes in this field too.

By filtering the disturbing presence of vessels are not solved all the problems which characterize the surface roughness measurement of wood. In practice surface qualifying is carried out by touch by hand (tactile measurement). Beyond the vessel removal quick and objective measurement would be carried out if there would be available a roughness parameter to describe one parametric the real estate of the surface. In this contest further investigations were carried out to decide would the primary P profile and its P_z parameter - figured out upon the R_z parameter - fulfill the expectation.

The actuality of the research was underlined by cases when the producer and the procurer couldn’t agree about the roughness convenience of oak table surfaces in absence of measuring method and parameter. The measurements performed for this PhD work have a regrettable limitation introduced by the stylus tip measuring instrument, which isn’t suitable for inline measurements. Taking into account the expected ransom of the instrument the method developed for vessels to be removed is indifferent from the way the profile points were collected. The method focuses on vessel filtration, making possible a wider game of wooden species to be estimated for machining quality reasons meanwhile delivers some unsuitable aspects of the traditional measuring technique.

Conclusions based on literature:

1. Reviewing the referring literature it shown up squarely that the big volumen publications appear mainly in German speech area and most of them deal with plaining and moulding and their correlations. Only a few papers deal with sanding.
2. From papers marks out that for wood surfaces first of all stylus tip instruments are used. Most authors leaning on metal industry standards and instruments use the disposable measuring equipment for wood surfaces without any critique. Only a few articles make questionable the suitability for wood surface measurements of the measuring instrument and method and suggest the need of review.
3. Some authors have the common opinion that based on Abbot curves parameters the anatomical and machining quality can be separated in form of Rvk and Rpk, Rk. In front of these considerations in many papers we meet the observation that the presence of big vessels makes the evaluation impossible. It’s noticeable that the evaluation problems caused by presence of big vessels generally are handled by the authors in two different ways: on one hand at the selection of the species to be investigated the big porous ones are let apart or on the other hand these species are recalled from the range of samples by the time of evaluation. There is a need for a method to be evaluated for a better surface quality evaluation of big porous species.
4. Related to the direction of measurements we can resume that the authors always choose the measuring direction perpendicular to the fiber. Their decision sometimes is supported by comparison measurements conducted parallel with fiber, other times it isn’t. On the measured profile perpendicular to the fiber they define the waviness and roughness profile. In the same time some authors mention the waviness like a so-called “chinematic roughness” measured along the fiber. This means that in case of wood makes no sense to define a wave deriving from machining perpendicular to the fiber. The measurements were performed with the Mahr instrument with the limitation that the measuring and computing instrument doesn’t allow the calculation of roughness parameters without deriving waviness and roughness from the primary P profile. In this context the assessment of waviness perpendicular to the fiber is a limitation attached to the measuring instrument.

5. The R parameters are computed only for the R profile although in case of wood this means a distortion in comparison with the real profile estate. There is a need for roughness parameters to be defined for the primary profile and the control of their suitability for to be qualifying parameters.

In the mirror of the above considerations the present work marks out the confirmation of the theoretical considerations the elucidation of contradictions and the evaluation of a new method based on the removal of vessels from the measured profile to make possible the evaluation of surface roughness of big porous species. First for measurements resulting primary P profile the establishment of roughness parameters was necessary based on the R parameters. The establishment and examination of “P” parameters is justified by the fact that the practical measuring method by touch by hand was to be interlocated. The adjacent profile to the tactile evaluation is the primary P profile. In order to compare the P parameters with R ones the removal of vessels and waviness filtration were performed. This way both the P_z and R_z parameters were investigated for the same profile and their correlation meanwhile the waviness was separated by means of a so called “robust filter” to avoid the distortions on R profile caused by the traditional Gauss filter. For the equilong profiles the W_z parameter was calculated established in the same way as Rz. There was examined the dependence of R_z and P_z from the sanding grain size for beech samples and a similar dependence was expected for other species too after the vessels were removed. The P_z/R_z quotient and its relation to W_z were investigated in search for a general context. Further more their relation was investigated for different type of sanding machines on acacia samples. To characterize the P profiles P_z parameter the $P'=W_z+R_z$ sum was investigated and their relation. Taking into account that the measurements need to be carried out for several times till the relative slope is minimized the effect of more measurements carried out in the same trace was investigated to elucidate the destruction effect of the tip.

The surface roughness of big porous species for different grain size was established after vessel removal to justify that after vessel filtration the roughness of the ground tissue (Molnár, 1999) is in good correlation with the grain size. Contrary no correlation can be justified!

II. The method of research – short summary

The investigations were performed mainly in labor circumstances and only some auxiliary tests were performed in factory. Sanding of samples took place in the training workshop of the University of West Hungary by portable sanding machine with SIA brand sanding canvas 75 x 533 mm, fulfilling the ISO 4586-2 with different grain size: 60, 80, 100, 120, 150, 180, 220, 240, 280, 320, 400, 500 and 600. Before use they were conditioned 72 hours on 23±2°C and 45% relative humidity. The korund grit was fixed electrostatic and by means of resins on the highly flexible canvas. The dust from the samples was brushed away by a fine haired brush connected to a vacuum cleaner.

For measurements performed in the same trace:

For all species samples sanded with 150 and 180 were prepared being the most frequent used grain sizes in the practice. In the same trace measurement repeated by 10 times were performed to examine how the roughness changes. Based on practical experience after 3-4 measurements the relative slope can be eliminated. On acacia repeated measurements were conducted by 20 times. **For the comparison of R_z and P_z samples produced on portable and contact sanding machines were prepared** 5 samples for each 120, 150 and 180 grain size.

Wood species	Grain size												
	60	80	100	120	150	180	220	240	280	320	400	500	600
Acacia	5	5	5	5	5	5	5	5	5	5	5	5	5
Oak	5	5	5	5	5	5	5	5	5	5	5	5	5
Ash	5	5	5	5	5	5	5	5	5	5	5	5	5
Birch	5	5	5	5	5	5	5	5	5	5	5	5	5
Beech	5	5	5	5	5	5	5	5	5	5	5	5	5

The chosen measuring instrument:

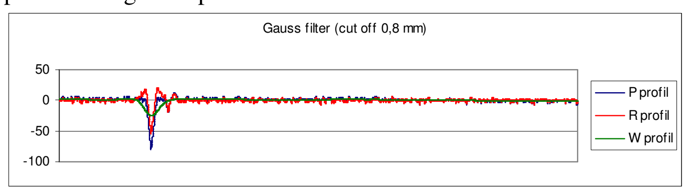
Perthometer S3P is a stylus tip instrument with 5 µm radius. Connecting the measuring instrument with a computer by RSC 232 cable it makes possible the data export by means of an auxiliary ASCII program. The auxiliary program was needed because the measuring instrument transmits the R roughness profile printed on paper, the computed parameters in digital form on monitor so as the unit doesn’t allows the access to the measured data.

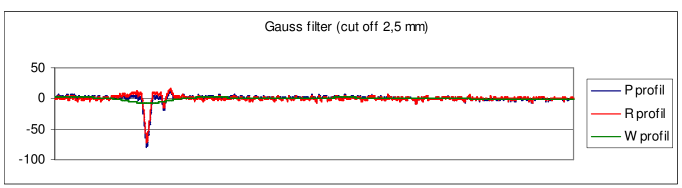
The vessel filtering Curve Cut program:

was written in Borland Delphi. The routines were made by Dr.Alpár Tibor based on algorithms defined by the author. After calling the data the program makes possible to figure the roughness profile, the frequency curve near different dissociations can be marked the portions to be removed and in elective way can be settled the replacement values. The program draws the roughness profile and the new frequency curve after the vessels are removed and offers the possibility for data to be saved in a convenient form. In a further optimation the program analyses in an inequality relation the data deriving from the waviness profile and makes possible the vessel stumps to be removed. After vessel filtration the new regression line is computed and the edges of the removed vessels are contracted. Henceforth with the use of a robust Gaussian filter the waviness is separated from the P profile and an R profile is generated. While performing the tentative measurements the traditional Gauss filter was only used for demonstrative reasons. The robust Gaussian filter did the separation of wave in order to eliminate the unfavorable accompanying phenomenon of traditional Gauss filters.

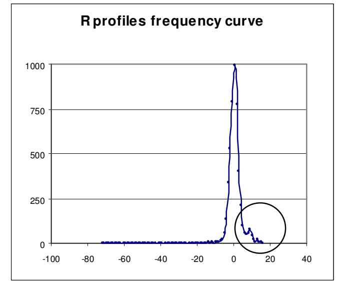
The unfavorable accompanying phenomenon of the traditional Gauss filter:

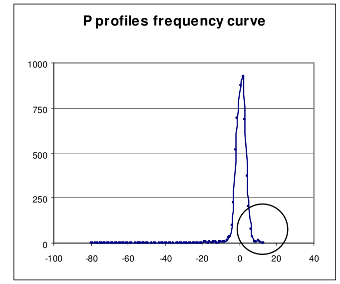
- When measuring big porous species in the neighborhood of big vessels we obtain a big amplitude waviness profile due to the functioning principle of the Gauss filter. In comparison with the real state the roughness profile is pushed up in the neighborhood of big pores. The phenomenon appears for both wavelengths but for a shorter wavelength the distortion is more remarkable. The measure of the unpleasant mutation basically depends on vessels depth and diameter but the number of pores and their arrangement along the measuring length influences it too.
- Filtering by means of Gauss filter the big porous species “push ups”, virtual hills appear on the R profile in positive direction relative to mean line. The R profile is a distortion of the real profile that shows material there where in reality doesn’t exist. The different measuring instruments compute the roughness parameters based on





R profile it’s questioned if the R profile derived from the traditional gauss filter is suitable for the quantitative evaluation of big porous species. The distortion of R profile is caused by the waviness filtration. Needs to be investigated the necessity of filtering and the interlocution possibility of the traditional Gauss filter.





- The pushed up vessel edges appear in a positive direction. The machining failure appears in positive direction too. In this sense the presence of vessels on profiles to be filtered with traditional Gauss filter worsen considerably the roughness parameter of machining.
- The pushed up vessel edges do appear on the frequency curve as well. Comparing the frequency curve of R and P profiles its conspicuous that in the positive range there are hills on the leg because of the pushed up vessels that are missing from the P profiles curve.

The robust Gaussian regression filter of the ground tissue

Describing the waviness of the ground tissue is equal with the problem to find the wave that doesn’t press close to vessels but maintains the characteristics of the ground tissue. To describe the waviness component the ISO/CTS 16610-31draft standard was used as forwarded to some experts at present time is under comment and review. He standard contains a method proposed by Brinkman that generates the wave by means of a robust Gaussian filter. The term “robust” covers the fact that the filter due to some theoretical considerations isn’t sensible to the so-called “outlier” data. The deep pores of big porous species don’t contribute to the characterization of processing quality and from this point of view they may be considered “outliers”. The robust Gaussian regression filter can be defined by the fallowing general arrangement:

$$\sum_{l=1}^{n}(z_l - w_k)^2 \cdot \delta_l^m \cdot s_{kl} \cdot \Delta x \rightarrow \min$$

With the weighting function:

$$s_{kl} = \frac{\sqrt{\pi} \cdot \Delta x}{\sqrt{\ln 2} \cdot \lambda} \cdot \exp\left(-\frac{\pi^2}{\ln 2} \cdot \frac{(k-l)^2 \cdot \Delta x^2}{\lambda^2} \right)$$

z_l – a profile height in the unfiltered profile
w_k – waviness value at index k
k – the index of the position relative to the centre of the averaging function
l – the index of the profile points
s_{kl} – the weighting function
δ_l^m - the additional vertical weight
m – the index of the iteration step
Δx – the sampling interval

In the first step when m=0 the wave is assessed by the means of the traditional Gaussian filter and the additional weight $\delta^{(0)}=1$ is applied to each data point. In subsequent iterations the value of δ is given by the condition:

$$\delta_l^{(m)} = \begin{cases} \left[1 - \left(\frac{z_l - w_l^{(m)}}{c_B^{(m)}} \right)^2 \right]^2 & \text{if: } \left| z_l - w_l^{(m)} \right| \le c_B \\ 0 & \text{otherwise} \end{cases}$$

The robust algorithm applies a regression filter iteratively to a dataset until the mean line is satisfactory. The robust filter extends by an additional vertical weighting δ at each data point. δ can take values between zero and one. c_B is a threshold value given by:

$$c_B^{(m)} = 4.4478 \cdot median\left| z_l - w_l^{(m)} \right|$$

Profile heights lying close to the mean line established in the previous iteration are multiplied by values of δ close to one, so almost their full value is included in a modified averaging function. Zero multiplies all the profile points further than c_B from the mean line. The number of the iteration steps isn't more than six due to the prescriptions of the standard. In the present

work three steps were performed. The waviness parameter of the robust regression arrangement:

$$w_k^{(m+1)} = \frac{\sum_{l=1}^{n} s_{kl} \cdot z_l \cdot \delta_l^{(m)}}{\sum_{l=1}^{n} s_{kl} \cdot \delta_l^{(m)}}$$

The introduction of the P profile in examination

There are a lot of standardized parameters for the study of roughness meanwhile a part of wood surfaces can not be qualified by means of surface roughness measurement. The main goal of the present work was to get closer to the qualifying of wood processing by means of roughness measurements with the obtained results. Taking into account that in practice qualifying of fine worked wooden surfaces is still done by sensing by hand – the introduction of the primary P profile is justified being the closest one to the real surface. Analysis is needed if the parameters of the P profile are suitable as qualifying parameters for the surface adjudicated by hand touch. The comparison is made upon the "R_z" and "P_z" parameters of the same profile. The measuring instrument computes the standardized R_z parameter on five evaluation lengths. To make the results comparable the computation of P_z parameters was made on five evaluation lengths contrary to the seven possible.

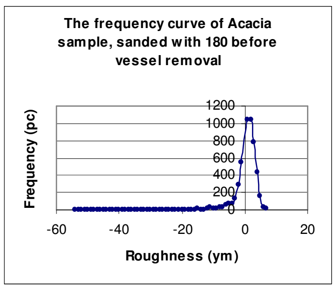
Arguments for vessel grooves to be removed

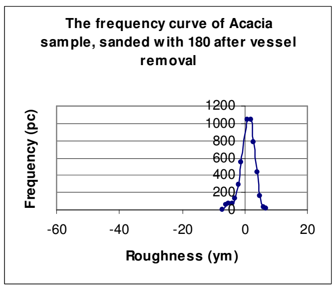
- Even in case of a good machining quality may occur that depending from the depth and number of vessels unfavorable roughness parameters result, making impossible the objective adjudication of the processing quality. The diameter and depth of the vessels alter with some order of magnitude from the characteristic values of the ground tissue and worsen considerably the roughness parameters computed.
- Due to the geometry of the stylus tip the vessel walls with the inclination smaller than 45° can't be assessed realistic. The shape of the vessels visualized on the roughness profile differs significantly from the real one.
- It is casual at which angle a vessel is cut through and where is positioned relative to the surface. In this sense considering them computing with them at the evaluation won't provide useful information.
- It is casual the diameter and deepness and the number of vessels appearing along the trace. This results that the roughness parameters can't correlate with the processing parameters.

- After vessel filtration the weaker quality of machining can be identified as R_{pk} in the positive range on the Abbot curve. Without vessel removal this value is occasionally mixed with the virtually pushed up vessel edges.
- The presence of vessels affects the regression line too.

The theoretical considerations of vessel removal

The vessel filtration is carried out upon the observation that the vessels appear in the negative range relative to the mean line. This way **the vessels can be identified on the frequency curve under the form of a characteristic hilly leg in the range of negative values**. On the frequency curve the processed surface of the ground tissue is identical with the most numerous roughness parameters. The Curve Cut program for vessel removal allows us to mark and replace with convenient values all the data of the range to be removed. Zero replaces the data belonging to vessels to avoid the appearance of false values.





The replacement of data

If the number of the data between the two consecutive vessel edges would be maintained as originally and would be replaced with the local values of the wave this wouldn't result the removal but the fill up of vessels. The action would result in an unfavorable change in Abbot curves shape, showing material where in reality doesn't exist. The replacement of vessel data to the local values of the wave by maintaining the original number of data would result a surface with "too smooth" portions on vessel places. Such a replacement would distort the value of Ra.
We can conclude that when removing the vessels it's unsuitable to maintain the original number of data.

Taking into account that the machining quality can be evaluated on the ground tissue while performing the filtration the data belonging to vessels are removed till the local values of the wave characterizing the ground tissue than the meeting point of the wave and vessel are unified. This way the phenomena appearing around the vessel edges, their real push up, tear or other deterioration contributes to the characterization of processing quality.

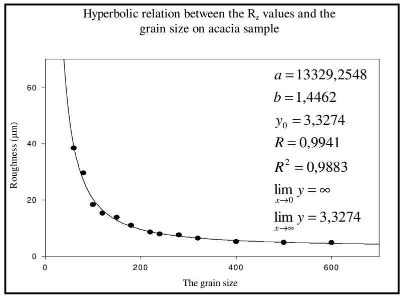
The profiles generated after vessel removal: P and R

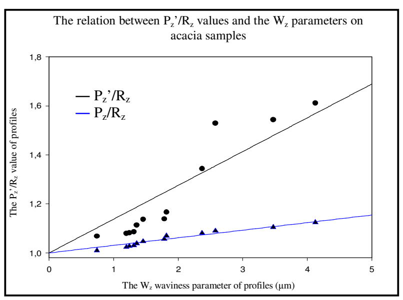
The P profile has as mean line the regression line. In the first step the position and the inclination of the regression line is function of number and position of deep vessels. As the roughness values are related to zero needs to be defined the regression line of the vessel filtered profile and has to be recalculated the new Y coordinates of the profile points in order to reduce the inclination to zero. Only the roughness parameters recalculated upon the newly assessed regression line are equal with the parameters of the profile characterizing the ground tissue without big pores. The P_z parameters were calculated after the regression line was recalculated and the profile data reinterpreted. After obtaining the vessel-removed profile the R profile was assessed by means of the robust Gaussian waviness filter.

III. The results of the research

On beach samples without large opened pores between P_z and R_z values and the grain size $y = y_o + a/x^n$ hyperbolic relation was found. Contrary for oak containing big opened pores neither P_z nor R_z correlated with the grain size of the sanding paper. In order to make possible the objective adjudication of processing quality a method was developed for the quick and precise removal of vessels:
The advantages of the method:
- it's objective and quicker than the existing ones
- functions for anyhow data points
- it's indifferent from the way the data points were collected
- the program allows us the assessment and evaluation of non standardized parameters too
- the program shows its advantages for long traces

Looking for a one parametric qualifying parameter the P_z, W_z and P_z/R_z parameters and their relations were investigated. After vessel removal the P_z and R_z showed $y = y_o + a/x^n$ hyperbolic dependence from the grain size. This way by vessel removal the expected relation was obtained between P_z, R_z and the grain size. The limit roughness of the investigated samples was around 5 µm for P_z and about 3-4 µm for R_z. Based upon the P_z/R_z relation investigations were conducted on acacia samples sanded on portable and contact sanding machine to compare roughness characteristics. In the P/R relation there is a 5% difference being a characteristic value. The P_z/R_z value calculated after the vessels were removed provides information about the waviness of the profile but doesn't provide any information about the roughness associated. Theoretic profiles with differing roughness may produce the same P/R. To provide further information about the relation of waviness and P/R the W_z parameter of waviness was calculated. For the (P_z/R_z,W_z)point pairs the line with $y = 1 + a \cdot x$ equation can be fit. The P/R relation can't be interpreted for values lower than 1, this results that the line has the border (0,1) on the left. Growing waviness resulted a linearly grooving P/R relation for each of the investigated samples. The content of P_z was further analyzed in order to evaluate the difference between the assessed P_z and the calculated P_z' being the sum between R_z and W_z (P_z'=R_z+W_z). For the (P_z'/R_z,W_z) point pairs the lines with the equation $y = 1 + a \cdot x$ can be fit. The difference equals the value of 1 µm at 10-12 µm waviness values. The difference results from the definition of P_z; R_z and W_z. The P_z; R_z and W_z are calculated as average for 5 sampling lengths. This results that for growing waviness grows the probability for a "peak" value of R_z to appear in a such a position on descending section of the wave that doesn't contribute to the calculation of P_{zi}. By defining the sampling lengths in more than five sections the correlation between of measured and calculated values would be better.





Looking for one parametric characteristic, investigating the P_z; R_z and W_z parameters the conclusion was found that there is no parameter suitable to characterize alone the state of the profile. The characterization of roughness needs two parameters (P_z/R_z; R_z). Near the R_z parameter that provides information about the roughness of the processed surface the P/R is an excellent parameter expressing sensual the measure in which the profile alters from the ideal R profile due to waviness and expresses in the same time the real state of the surface by the presence of the P_z parameter.

IV.Thesis – summary of new results

1. A method was developed for the vessels to be marked and removed from the profile till the local values of the wave characterizing the ground tissue. The method is indifferent from the measuring instrument the data were collected with and from the measuring length. Its availability for quick evaluation is principally shown for long traces. The method makes possible the objective measurement and evaluation of processing roughness of big porous species.
2. Searching for a quick and objective qualifying the P profile was chosen for further examination. A suggestion was made for a new regression line to be assessed on the data remaining after vessel filtration. Only the roughness parameters recalculated upon the newly assessed regression line are equal with the parameters of the profile characterizing the ground tissue without big pores. It's unfavorable to maintain the original number of data instead the removed vessels the vessel edges should be unified. Investigating the P_z/R_z quotient in function of the W_z parameter linear dependence was found. The point-pairs fit well the $y = 1 + a \cdot x$ line. The slope of the line "a" based on my investigations is of 0,01 µm order and depends from the components of the ground tissue and in this sense from the wood species too.

3. To the same R_z values may belong different surface geometries so the standardized R_z one parametric characteristic doesn't describe full-scale the state of the profile. Investigating the Pz, Rz and Wz parameters I've found that there isn't one parametric characteristic for qualifying to fulfill the characterization of the state of the profile by itself. I suggested the description of roughness to be done by two parameters: (P_z/R_z; R_z).

4. Derives from the way of evaluation that increasing the number of sampling lengths the P_z value converges to $P'_z = R_z + P_z$. The difference between the measured P_z and the calculated P_z' investigated in relation with W_z concluded that increasing wave results increasing difference, the context is linear by $\boldsymbol{y} = \boldsymbol{1} + \boldsymbol{a} \cdot \boldsymbol{x}$. The characterization of the profile ameliorates if the number of sampling lengths is settled in more than seven sections.

5. Using the evaluated vessel filtering method on acacia, oak, ash and birch, four big porous species hyperbolic dependence was found between the roughness of the ground tissue and the sanding grain size on P and R profiles as well. Rising the grain size to infinite, on different species the roughness on P profile arises around 5,1 and 6,3 µm, for R profile the threshold value arises around 3,3 and 5 µm. The above values provide information about the anatomical roughness of the species alter from the last one only in measure in which the stylus tip instrument approximates the real surfaces characteristics.

V. Publications connected to the subject

1. Csiha, Cs. (1998): Felületkezelő technológiai sorok összehasonlító elemzése KIPA módszerrel. (Doktori szigorlat)
2. Csiha, Cs. (1999): Wood surface evaluation – differenciation between vessels and other forms of roughness. Proceedings of the Fourth International Conference on the developement of Wood Science, Wood Technology and Forestry Missenden Abbey.
3. Krisch, J. – Csiha, Cs. (2000): Analysing wood surface roughness – using an S3P Perthometer and computer based data processing, Badania dla meblarstwa XIII, Poznan, pp. 145-155, 2000
4. Csiha, Cs. - Krisch, J. (2000): Vessel filtration – a method for analisyng wood surface roughness of large porous species, Drevarsky Vyskum 45(1): 13-22, 2000
5. Dr. Szabó, I. – Csiha, Cs. (2003): Ragasztási és felületkezelési folyamatok. Egyetemi jegyzet.
6. Csiha, Cs. – Alpár, T. (2003): Nagyedényes fafajok felületi érdességének értékelése. Faipar LI. Évf. 2003/1., pp.:11-16.
7. Csiha Cs. (2004): Measurement of wood surface roughness of big porous species. COST E18 Coatings on wood, Symposium on measurement methods, Coating Consultancy Proceedings, Copenhagen

Oral presentations:

1. Csiha Cs. (1996): Bevonatok repedezése és kiváltó okai. Szakmai napok Székelyudvarhely, 1996
2. Csiha Cs. (1997): Felületi repedések kiértékelése számítógépes képelemző módszerrel. Szakmai napok Marosvásárhely, 1997

Final report not placed in library:

1. . Síkvidéki nyár és fenyőültetvények termesztésének és a faanyag minőségének összefüggései. OTKA, Faanyagismerettan Tanszék (1994-1997):
2. High quality products from Black Locust, OTKA, TGYI - Zólyomi Egyetem (1998-1999)
3. Piacképes bútorcsalád önálló kifejlesztése a hagyományos felületkezelés és kézi festés, patinázás és öregítő technológiák együttes alkalmazásával. OTKA - Hubertusz (1999-2000)
4. Bevonatok minősítő rendszerének kidolgozása, NKFP, (1999-2001)

5. Beltéri termékek fejlesztése hazai faanyag bázison (ragasztási, színhomogenizálási, felületkezelési kísérletek alapján), tömörfa parketták, frontelemek előállítása, NKFP, TGYI (2002-2003)

6. Kültéri bútorcsalád előállítása tömörfából (akácból) technológiai, szerkezet- és formatervezési kérdések megoldása. Különös figyelemmel a színhomogenizálásra és a környezetbarát felületkezelésre. (2002-2003)