# Innovative Method for Assessing the Quality of Special Wood Products during the Production Process

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**Abstract**

Innovations in the assortment of special wood products made by small manufacturers, and not by major manufacturers in terms of quality and environmental credentials, enables them to compete successfully on the market. For the final phase of the production process, these products require a precisely chosen surface finishing treatment.

The purpose of wood treatment is to protect a specific adherend against the adverse effects of external influences, as well as mechanical, chemical and biological damage. The requirements for the quality of the surface treatment are dependent on the function and purpose of a particular product.

At present, beyond surface characteristics, there are no other evaluation criteria that take into account the diverse morphological characteristics of wood, e.g. reflectance as a result of the surface reaction of wood to the application of different types and layers of coatings.

The research presented in this article focuses on determining the most important qualitative criteria with regards to the surface treatment of special wood products (by assessing the morphological characteristics of the wood ´ s surface by means of an experimental optical laser) during the production process of these products, which are produced by a limited number of small manufacturers, are produced in an environmentally friendly way, and are competitive and sustainable.

**Keywords:** qualitative criteria, production process, innovative optical laser

## Introduction

At present, the issue of the impact of environmentally friendly technologies is still relevant. Within this context, it is necessary to build an optimal production chain, one that is effective, but environmentally friendly, yet economically efficient, competitive and sustainable in the market, and which delivers products according to customer demands as a result of innovative production processes (Brashaw 2009; Lindermann et al. 2013, Ružinská 2015b, 2018b).

The production process, as the main activity of a production company, directly influences the efficiency of a business and the ability of its products to compete under competitive market conditions (Caha 2017; Grewal 2008; Synek et al. 2007; Vochozka et al. 2011, 2015; Lindermann et al. 2013). This relies on the minimisation, respectively optimisation of inputs and the maximisation of outputs.

For small producers in these markets to supply customers with desirable products requires a lot of effort and innovation. Their success in markets dominated by large manufacturers depends on the uniqueness of their products, effective management of quality, environmental credentials, and the requirements of customers (Grewal 2008; Guerrero et al. 2017; Lindermann et al. 2013; Sujová et al. 2015).

The innovativeness of special wood products is determined by the identification of all the decisive factors in the production management process. The most important factor is the preparation of the substrate, i.e. wood for subsequent surface treatment. Of similar importance is the selection of the desired product quality criteria. However, although relevant qualitative criteria exist for a wide range of products, such as furniture or construction materials, this does not apply to special wood products (sports articles, toys, jewellery, music instruments, gift items, etc.) (Kalendová 2004; Kúdela and Liptáková 2005; Jabłoński et al. 2009; Sedliačik et al. 2013; Zhong et al., 2013; Badida et al. 2016; Seabra et al. 2017; Ružinská 2018a).

The aim of the research presented in this article was therefore to empirically determine the most important qualitative criteria for the evaluation of the surface finishing treatment of special wood products. The focus was on the application of our own experimental method (optical laser) for assessing the surface characteristics of wood. This is considered important because it is the surface of the wood and its subsequent surface treatment that determines all its other important properties (physico-mechanical, chemical, resistance, thermodynamic and specific) during its lifetime and under the conditions of use by consumers.

### Quality management during surface treatment of special wood products

The definition of quality within the framework of quality management usually changes in line with changes in production processes and the conditions in which products are made. It should (also) be taken into consideration that customer demands change over time, which suggests that quality does not remain unchanged (Synek et al. 2007).

Every product has its own qualitative characteristics, i.e. relevant product features that serve to describe its quality. These features should form the properties of products that significantly meet the demands of consumers and positively affect their satisfaction. These include: usability, functionality and performance, equipment, reliability, compliance with standards, durability, ecological credentials, and design (Sedliačik et al. 2013; Sujová et al. 2015; Ružinská 2018a).

For good quality management it is important to understand what quality criteria are essential, to determine the methods for measuring and testing them, and, where appropriate, to find alternatives and understand the relationships between them. It is only in this way that the quality of the products produced by manufacturers will meet consumer's requirements (Vochozka et al. 2011, 2015; Lindermann et al. 2013).

For this research, the product-oriented quality management approach was applied, whereby the definition of quality is indicative of both accuracy and measurability; current principles of quality management during the surface treatment of wood products were also taken into consideration (Ružinská et al. 2014 a, b, 2015 a, b, 2018 a, b).

Product-oriented definitions are based on whether a product has the properties as prescribed in the accompanying technical documentation. Any increase in the level of a particular product parameter is understood to reflect an increase in its quality. However, quality defined in this way leads to quality assurance activities that are purely focused on technical control. This is evidenced by the many key standards or mandatory methods for assessing the primary (mechanical, physical, chemical, resistance, ecological, hygienic, specific) characteristics of surface treated wood products (Kalendová et al. 2004; Kúdela and Liptáková 2005; Ružinská 2014a, 2018a, b; Sain et al. 2006; Salmén et al. 2014; Zhong et al. 2013).

These standardised qualitative criteria only apply to defined groups of wood products (furniture, building and carpentry, woodworking products), but do not exist for special wood products.

An indispensable part of protecting wood products is the surface finish, which can extend the life of wood and highlight its natural beauty. It is important that the method and type of surface treatment be determined correctly. Wood is a "living material" with natural beauty, which can be accentuated by the appropriate surface finish, but which can see its utility value fall and lifetime shortened with an inappropriate one (Sedliačik et al. 2013; Madhoushi et al. 2017).

The primary goal of wood treatment is to protect a specific adherend against the adverse effects of external influences, as well as mechanical, chemical and biological damage. An important aspect of this is the need to increase the aesthetic appearance of wood products in their final form and the need to preserve all of its other quality characteristics (mechanical, physical-chemical, ecological, biological, resistant and specific). After all, the sale of wood products depends on this and a lack of disturbing defects (Kalendová et al. 2004; Berenjan et al. 2012; Ružinská 2014a, 2018a, b; Zhong et al. 2013).

The properties of wood primarily affect the surface treatment of the wood. However, the influence of the chemical composition of the type of coatings used is also significant, as are other factors that influence the interaction between the wood and the coatings during their application and/or curing (Seabra et al. 2017; Zhong et al. 2013; Salmén et al. 2014).

Wood can be characterised as a homogeneous, porous-capillary, limited swelling colloid. The porous character of wood is the result of its morphological properties. Wood is an extensive capillary system with cavities. The different morphology of the wood surface and its various properties in individual anatomical directions is based on the knowledge of a specific adherend (wood) having a heterogeneous, anisotropic polymeric composition (Sain et al. 2006; Zhong et al. 2013; Madhoushi et al. 2017).

The differences in the surface roughness (as an important morphological characteristic) of wood in different anatomical directions, which is an important factor during the surface treatment process, are also taken into account in the resulting qualitative properties of surface finishing (Kúdela and Liptáková 2005; Boruszewski et al. 2012; Salmén et al. 2014; Zhong et al. 2013; Salmén 2014; Ružinská 2018a).

The requirements for the quality of the surface treatment are dependent on the function and purpose of a particular product. In addition to assessing the characteristics of the appearance of different types of coatings, it is important to know the geometry of the wood, especially its surface roughness, because it is at this interface where the interaction takes place between the substrate and the applied coating (Kúdela and Liptáková 2005; Brashaw 2009; Zhong et al. 2013; Salmén 2014; Ružinská 2014a, 2015a, 2018a).

At present, beyond surface characteristics, there are no other evaluation criteria that take into account the diverse morphological characteristics of wood (e.g. reflectance as a result of the surface reaction of wood to the application of coatings). Such criteria would help to clarify the interactions between wood and coatings because this interface conditions the success and appearance of the resulting special wood products.

## Materials and Methods

### Proposed primary quality characteristics for the surface treatment of special wood products

This research focuses on the application of an experimental method (optical laser) for the assessment of the surface characteristics of wood, since it is the surface of the wood and its subsequent surface treatment that determines all its other important properties (physico-mechanical, chemical, resistance, thermodynamic and specific) during its lifetime and under the conditions of use by consumers.

The assessment of the quality of the surface treatments is based on a comprehensive set of criteria, including those in previously published research in the field (Ružinská 2014a, b; 2015a, b; 2018a, b).

**Experimental optical laser method for quality assessment of surface treatment of special wood products**

The *optical laser method* is an alternative, non-destructive method for assessing the surface quality of wood as a specific adherend. The method involves the evaluation of the intensity of reflected radiation from a test body during surface treatment processes. The intensity of the reflected radiation (in lux units) is quantitatively measured from the surface of the test samples after the application of each individual coating in order to determine the changes in surface quality during each stage of the surface treatment process (Ružinská 2018a).

Helium-laser (He-Ne) radiation was directed at different angles (20°, 40° and 60°) to the anatomical directions (perpendicular and parallel) of the wood fibres. The method was applied to test samples that were treated with different coating systems based on natural and industrial oils and waxes. The results are presented in Table 2.

The proposed method was applied to wood products (sports articles, toys, jewelery, music instruments, gifts, etc.) classified as special. It is intended to complement findings (standardised under profilometric methods) on the morphological characteristics of wood during production processes in terms of its impact on the qualitative changes in special wood products, with a view to improving the efficiency of technological production operations.

## Materials

The research on the surface treatments presented here is based on the application of environmentally friendly coatings to special wood products.

In total, 7 types of coating systems based on natural and industrial oils and waxes were used for the surface treatment of beech wood samples. The oil and wax based coatings did not contain VOCs (volatile organic compounds), which are present as additives in most commercially available coatings, and which are classified as hazardous for the health (Roffael et al. 2012; Berenjan et al. 2012; Ružinská 2015a, b).

The different coating systems applied are listed in Table 1.

Table 1: Identification and description of coating systems

| Coating system | Description of coating system |
|---|---|
| WO-1 | Oil wax |
| WO-2 | Industrial wax |
| WO-3 | Special oil wax |
| A1 | Modified wax |
| A2 | Modified wax + PUR water soluble lacquer |
| OL | Natural flaxseed oil with waxes |
| AR | Water dispersion with wax |

Source: Author

## Results and Discussion

### Primary quality characteristics of surface treatments of special wood products

The assessment of the quality of the surface treatments is based on a comprehensive set of criteria, including those in previously published research in the field (Ružinská et al. 2014a, b; 2015 a, b; 2018a).

For this research, the following qualitative criteria are considered to be key to the assessment of the coatings applied to special wood products during surface treatment processes (see Figure 1):

- Properties of the coatings:
  - chemical composition of the film-forming components
- Properties of the wood as an adherend:
  - morphological properties of the wood
  - chemical composition of the wood
  - internal and external wood surface
  - physical and mechanical properties of the wood
- Interaction of wood and coatings:
  - wetting of wood surface
  - penetration of coatings into the structure of the wood
  - phase interface during application and drying (curing).

The morphological properties of wood as an adherend is one of the most important factors influencing the quality of wood surface treatments. Special attention was therefore paid to this qualitative characteristic. The proposed non-destructive experimental laser method provided complementary data on the changes in the profile characteristics of special wood products during surface treatment processes. This not only gave valuable insights into the morphological (profileometric) characteristics of adherence (surface roughness), but also into the optical characteristics of the surface treatments (gloss measurement, coating defect identification) (Ružinská 2015a; 2018a).

The results presented in Table 2 and Figures 2-4 show that the intensity of the reflected narrow beam of laser radiation (He-Ne) not only depends on the quality of the type and layer of coating, but also on the interaction with the substrate (wood) and the anatomical direction (perpendicular and parallel to the direction of the wood fibres).

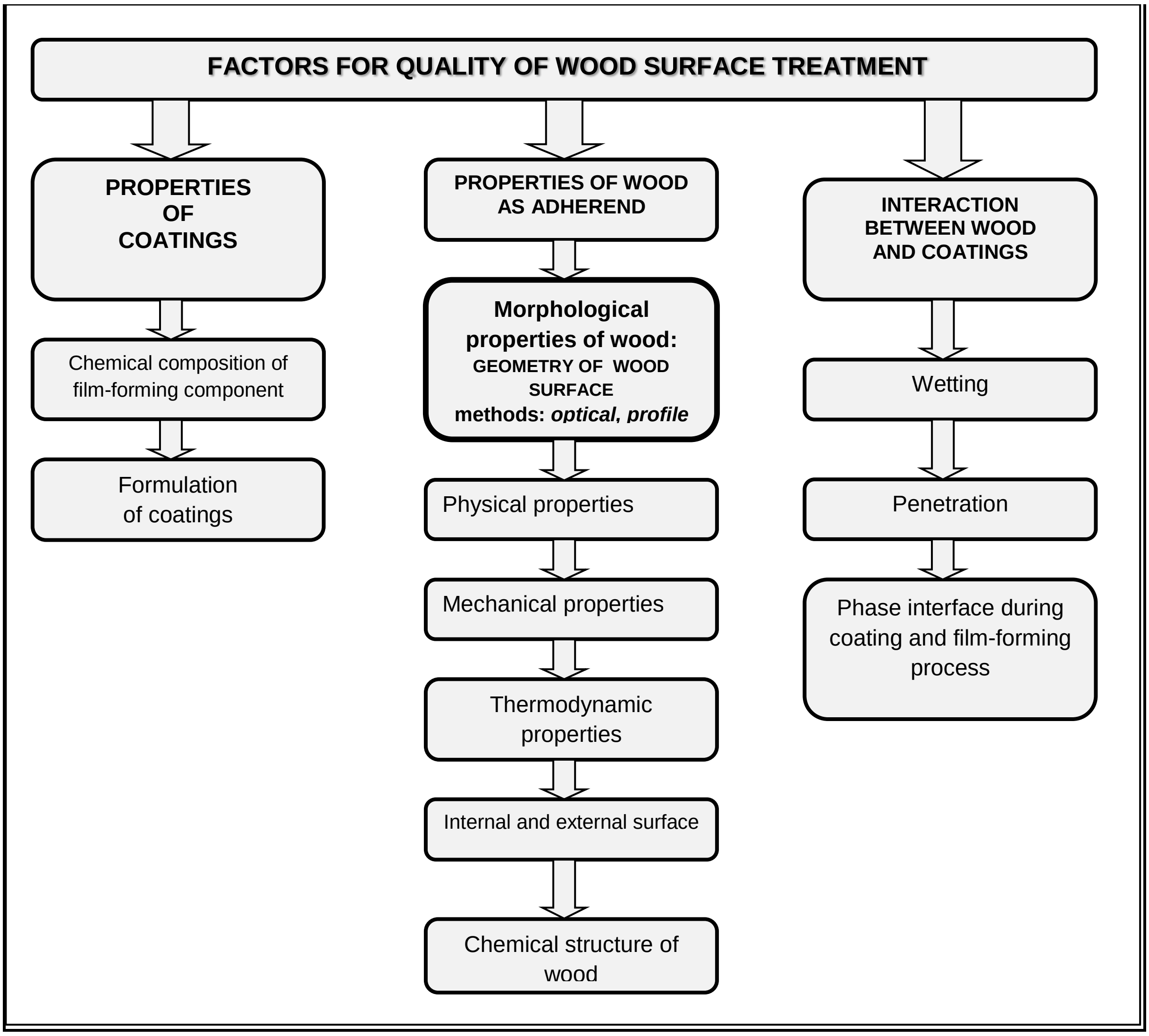
The beam of the He-Ne lasers behaved in response to the test samples as follows:
For test samples with non-milled surfaces there was a diffuse reflection, as a result of which the intensity of the reflected radiation to the ultrasonic sensing device was low. In contrast, milled test samples contributed to a reduction in surface roughness, which resulted in an increase in the amount of reflected radiation from the substrate.

The application of the first coat caused an increase in the amount of reflected radiation from the test samples, which can in all probability be put down to the fact that it acts like a mirror. In contrast, pre-treatment of the wood prior to the application of the first coat caused a reduction in the amount of reflected radiation from the test samples. This is possibly due to the disruption of the integrity of the coating layer, as reflected in the decrease in the experimentally evaluated characteristics.

The second layer of coating can be considered final from the point of view of the applied coating system. From this it can be deduced that the second layer of coating is the final one.

Pre-treatment prior to the application of the second and third coat resulted in a decrease in the values of the measured characteristics. This is probably due to the complex process of reflection of the beams from both the substrate and the layers of coatings.

Picture 1: Factors determining the quality of wood surface treatments




Source: Ružinská 2018a

The evaluated reflection values for the third coat showed a slight increase in the observed property compared to the values recorded after the application of the second coat. This implies that three layers of oil- and wax-based coatings are necessary from the viewpoint of wood geometry, which was subsequently confirmed by the comprehensive results with regards to the physical, mechanical, chemical, optical, appearance, resistance and thermodynamic and thermal properties of the surface treatment (Ružinská 2014b; 2015a; 2018a).

The results of the statistical evaluation of the observed characteristics and influences revealed that: i) the anatomical direction of the surfaces of the test samples is statistically significant at the selected interval levels (see Table 2 and Figure 2); ii) the interactions between the layers of coatings for each of the coating systems is less significant; iii) the least significant impact is the influence of the coatings on the reflectance values of the surfaces of the test samples (see Figure 3 and 4).

After analysing the most important factors influencing the quality of the surface treatments of special wood products, it was determined that the main evaluation criterion is the morphological characteristics of the substrate and that this should be monitored during the surface treatment of these products.

For the evaluation of the monitored morphological characteristics, an experimental, non-destructive, optical laser (He-Ne laser) was used. The measured results were subjected to a statistical evaluation. The reflectance results, according to surface geometry, angle settings (20°, 40° and 60 °) and selected variables are presented in Table 2.

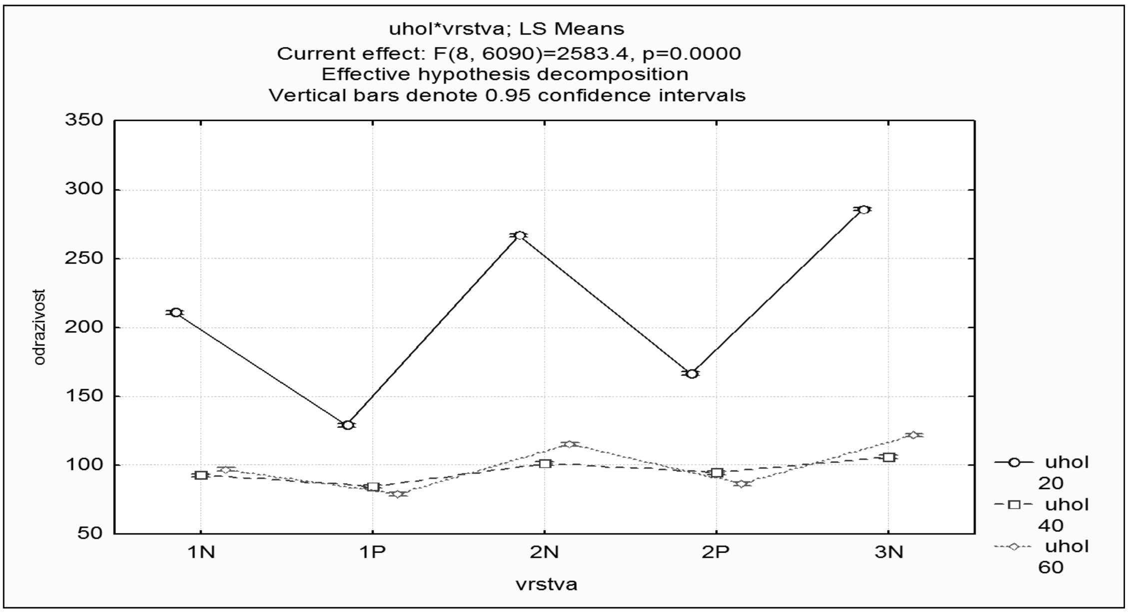
Table 2: Statistical evaluation of the mean reflectance values

| **Description of variable** | **SS** | **Degr. of freedom** | **MS** | **F** | **p** |
|---|---|---|---|---|---|
| INTERCEPT | 116099237 | 1 | 116099237 | 738162 | 0.000 |
| angle | 18241654 | 2 | 9120827 | 57990 | 0.000 |
| direction | 348966 | 1 | 348966 | 2219 | 0.000 |
| coat | 5283710 | 6 | 880618 | 5599 | 0.000 |
| layer | 4754055 | 4 | 1188514 | 7557 | 0.000 |
| angle*direction | 172098 | 2 | 86049 | 547 | 0.000 |
| angle*coat | 4544299 | 12 | 378692 | 2408 | 0.000 |
| direction*coat | 92897 | 6 | 15483 | 98 | 0.000 |
| angle*layer | 3250593 | 8 | 406324 | 2583 | 0.000 |
| direction*layer | 5026 | 4 | 1256 | 8 | 0.000 |
| coat*layer | 991544 | 24 | 41314 | 263 | 0.000 |
| angle*direction*coat | 94598 | 12 | 7883 | 50 | 0.000 |
| angle*direction*layer | 14120 | 8 | 1765 | 11 | 0.000 |
| angle*coat*layer | 1303557 | 48 | 27157 | 173 | 0.000 |
| direction*coat*layer | 49499 | 24 | 2062 | 13 | 0.000 |
| angle*direction*coat*layer | 114513 | 48 | 2386 | 15 | 0.000 |
| ERROR | 957845 | 6090 | 157 | | |

Notes**:** SS - squared sum of deviations caused by the variable, its interaction and random factors; Degr. of Freedom - degrees of freedom (interaction of factors with regards to the dispersion of random factors); MS - scatter caused by the variable, its interaction and random factors; F – F-test; p - significance levels in the F-test.

Source: Author

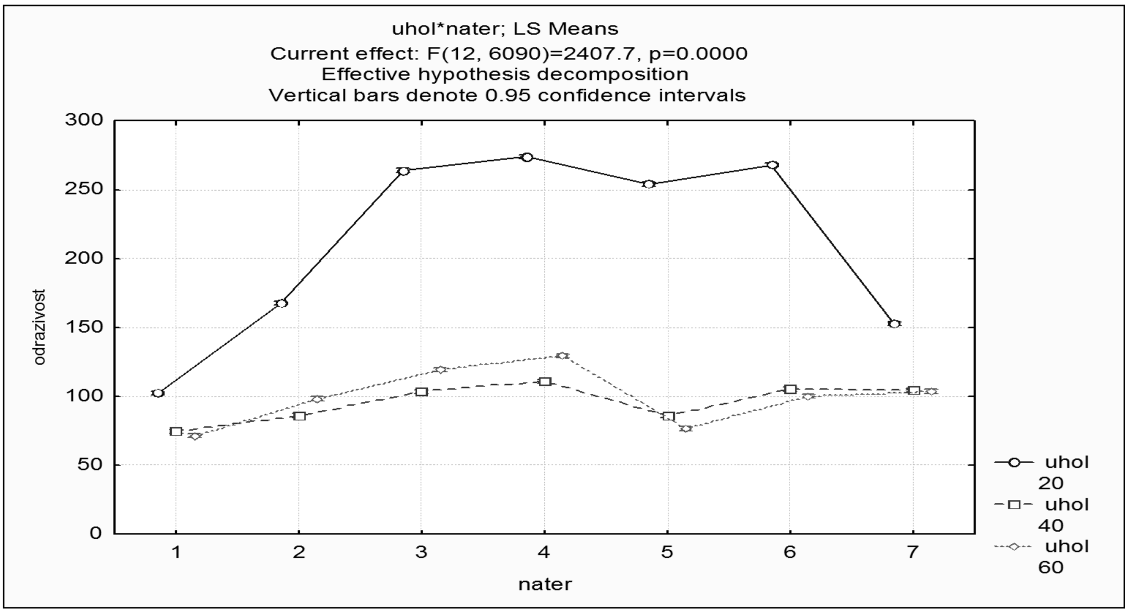
Figure 1: 95% confidence interval for mean reflectance values [lux] for angle of interaction (20°, 40° and 60°) and coat (layer)




(Notes: 1N – first coat, 1P – milling of first coat, 2N – second coat, 2P – milling of second coat, 3N – third coat; odrazivosť – reflectance; vrstva – coat (layer); uhol – angle 20°, 40° and 60°).

Source: Author

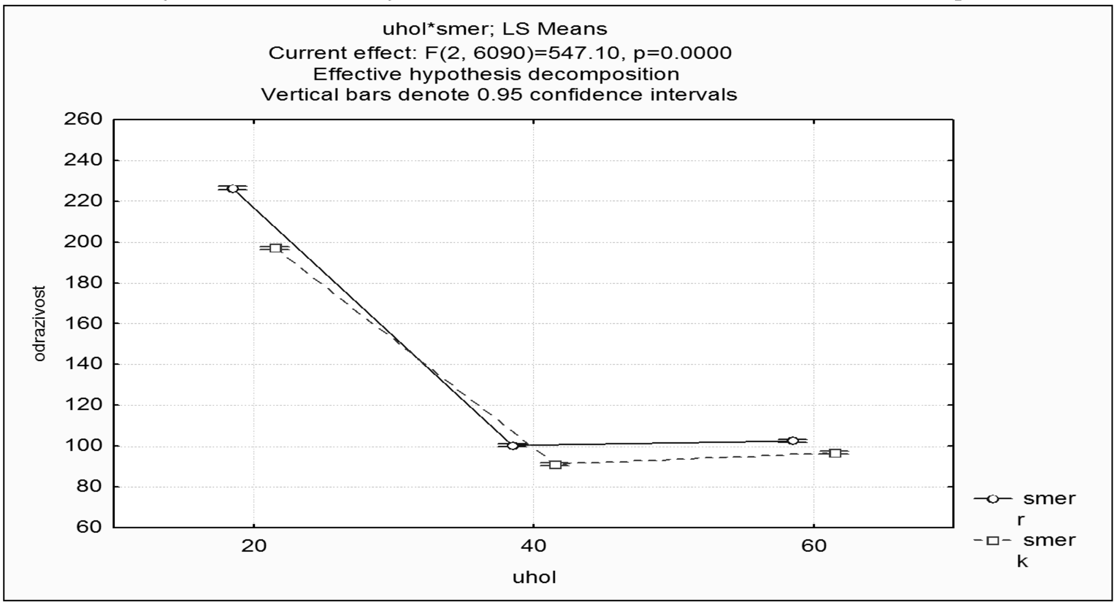
Figure 2: 95% confidence interval for mean reflectance values [lux] for angle of interaction (20°, 40° and 60°) and applied coatings




(Notes: Coatings:1 – OS; 2 – ID; 3 – HW; 4 – OL; 5 – AK; 6 – AKV; 7 – AR; odrazivosť – reflectance; náter – coating (type); uhol – angle 20°, 40° and 60°)

Source: Author

Figure 3: 95% confidence interval for mean reflectance values [lux] for angle of interaction (20°, 40° and 60°) and anatomical direction of the test samples




(Notes: odrazivosť – reflectance; uhol – angle 20°, 40° and 60°, smer r – parallel to the direction of the wood fibres, smer k – perpendicular to the direction of the wood fibres)

Source: Author

## Conclusion

The research focused on determining the most important qualitative criteria with regards to the surface treatment of special wood products (by assessing the morphological characteristics of the wood´s surface by means of an experimental optical laser) during the production process of these products, which are produced by a limited number of small manufacturers, are produced in an environmentally friendly way, and are competitive and sustainable.

The research focused on the application of an experimental method (optical laser) for the assessment of the surface characteristics of wood, since it is the surface of the wood and its subsequent surface treatment that determines all its other important properties (physico-mechanical, chemical, resistance, thermodynamic and specific) during its lifetime and under the conditions of use by consumers. Based on the proposed experimental laser method, it was possible to determine the optimal number of coating layers for each coating system and to monitor the qualitative characteristics of the wood during the individual stages of the surface treatment process.

The results can be considered as an innovative application of laser radiation in the study of coatings during surface treatment, in particular with regards to the monitoring of changes in the characteristics of various wood substrates in terms of their surface properties and important qualitative indicators.

The evaluation of the results generated through the use of this alternative laser method confirmed the results of surface roughness evaluations according to the standard profile method (Ružinská, 2015a; 2018a), but provided more detailed and comprehensive knowledge of the surface properties of the substrate (wood), whilst enabling a relatively rapid and objective evaluation of its quality during surface treatment processes.

The proposed criteria and innovative monitoring method for determining the quality of coatings for special wood products should contribute to speeding up the evaluation and objectification of quality in practice.

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