Determination of Gloss in Decorative Coated Wood-based Composite Boards by Image Processing Method

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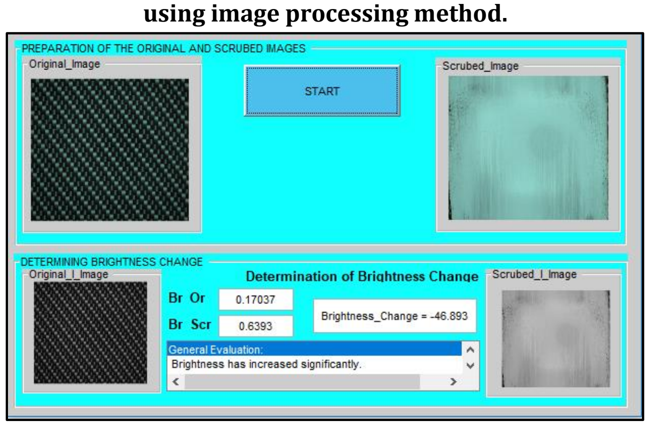
GRAPHICAL ABSTRACT

Coated Samples were Prepared.

Acetone Scrubbing Completed in 5.4 Minutes.

Abrasion in Samples After Scrubbing with Acetone.

Measurement of brightness changes on sample surfaces using image processing method.



Determination of Gloss in Decorative Coated Wood-based Composite Boards by Image Processing Method

Ferzan Katırcıoğlu,[a] Mehmet Budakçı,[b] and Serdar Kaçamer,[c,*]

Ultraviolet (UV)-cured coating and water transfer printing (WTP) are popular organic coating techniques offering aesthetic and functional benefits for wood-based panels. This study considered the gloss change of medium density fiberboard (MDF) panels, which were coated with WTP and UV printing processes. Image processing was used before and after being exposed to some domestic cleaning agents. A carbon fiber-patterned organic finish was applied to the surfaces of the prepared sample panels followed by scrub-testing with various domestic cleaning agents in compliance with Turkish Standards (TS) EN ISO 11998. The image processing based scrubbing tester (IPBST) developed in this study was used for the scrubbing process. Digital images of the samples were captured before and after the scrubbing process, and the Red-Green-Blue (RGB) color model was converted to the Hue-Saturation-Intensity (HSI) model for analysis. The *I*-channel in the HSI system was used to calculate the average gloss values, which were compared to results from the BYK-Gardner Spectro-Guide 45/0 device. Pearson correlation analysis indicated a robust and statistically significant correlation of 0.71. As a result, the image analysis-based gloss evaluation method has been shown to enable a more comprehensive evaluation of surface quality by providing fast, non-contact, and detailed analysis.

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Keywords: Image processing technique; Gloss test; UV printing; Water transfer printing; Organic coatings; Scrub tester; Lacquer product; Medium-density fiberboard (MDF)

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INTRODUCTION

Ultraviolet (UV)-cured printing and water transfer printing (WTP) techniques are extensively utilized today as modern surface coating techniques to increase the aesthetic and durability properties of various materials (wood, plastic, metal, composite, *etc*.). Water transfer printing, also known as hydrographic coating, is a very successful technique used to apply two- or three-dimensional patterns to material surfaces (Sarkodie *et al*. 2018; Kaçamer and Budakçı 2023; Li *et al*. 2024). The UV-cured printing technique involves the hardening of ink or varnish layers on material surfaces using ultraviolet rays. These coating processes provide protection against scratches, chemical effects, and UV rays, while also providing a visually appealing appearance (Schwalm 2006; Kudo *et al*. 2017).

Water transfer printing (hydrographic printing) and UV printing are two printing technologies preferred in different applications. Water transfer printing is ideal for applying patterns to complex surfaces, especially in 3D objects. Its advantages include high durability, wide pattern variety, and versatile material compatibility. However, being a chemical-based process can lead to environmental risks, and the application process requires experience and equipment. UV printing, on the other hand, is digitally based; the main advantages are that the ink dries instantly with UV rays; the process results in high resolution and can be used on various surfaces (wood, plastic, glass). Its disadvantages are the high initial cost, the flat structure of the panel to be printed, the risk of cracking in thick ink layers and the possible long-term effects of UV rays on human health (Schwalm 2006; Harnois *et al.* 2020; Hou *et al.* 2024; Todorova *et al.* 2024).

Before each new paint, coating, and varnish material is introduced to the market in the sector, tests such as roughness, color, hardness, adhesion, gloss, *etc*. are assessed to determine its performance (Karabay 2006; Köksal 2024). Moreover, prior to these evaluations, it is exposed to both natural and synthetic aging processes such as outdoor weathering, rain or snow impacts, UV effects from sunlight, accelerated aging, salt corrosion, abrasion, thermal cycling, domestic cleaning agents, *etc*., which create various deformations in the protective layers (Özdemir *et al*. 2018; Bayraktar and Kesik 2022; Büşra *et al*. 2022).

Nowadays, new products coming off the production line are tested for resistance to domestic cleaning agents. There are many different methods or devices that perform an accelerated aging process for this purpose. Recently, it has been recognized that traditional scrubbing devices are used to perform a scrubbing process with chemical liquids (accelerated aging) in order to test the quality of paint, varnish, coating, *etc*. materials on sample panels surfaces. However, these scrub testers cannot test the transformations that occur on the surfaces of the samples after the scrubbing process. In other words, it is seen that they cannot show any reference point and produce a report or output. For this reason, researchers have to use different industrial testing devices to measure changes in material surfaces after the scrubbing process, such as color, gloss, roughness, abrasion, adhesion, scratching, *etc*. (Kaçamer 2024; Kaçamer *et al*. 2025).

Scrub testers simulate real-life wear conditions by rubbing the surface at a certain pressure and speed to test the wear resistance of material surfaces (Özdamar 2016). As a result of the scrubbing processes (a series of abrasions or aging) carried out using domestic cleaning agents and scrub tester devices according to the standard conditions determined within the scope of the research, it causes the material surfaces to wear out in a short time and causes damages such as abrasion, scratching, color, gloss, *etc*. As a result of the scrubbing process, industrial test devices enable the classification of the quality of the newly produced coated or painted material surfaces with the measurements taken (Smith *et al*. 2017; Kaçamer *et al*. 2023).

Gloss testing of newly produced wood-based composite panels is of critical importance to evaluate the aesthetic and functional properties of these materials. While traditional gloss measurement methods are usually performed using glossmeters, image processing techniques have emerged as an important alternative in this field in recent years. In the literature, by using image processing methods in the gloss analysis of wood-based composite panels, results that show high correlation with glossmeter results were obtained (Zhang *et al.* 2019). In a different study, image processing techniques were used in the gloss analysis of wood surfaces after Computer Numerical Control (CNC) processing and it was stated that these methods gave faster and more precise results than traditional methods (Park *et al*. 2020). In another study, research was carried out using image processing method in surface decoration applications of wood-based panels. Due to noise generated in wood grain reproductions, scanned images cannot be employed directly. A noise filter and a sharpening filter are used to reduce noise and maintain or enhance image sharpness. To conduct an objective assessment of denoised and sharpened images, two evaluation functions were applied: the Roberts gradient function (RGF) and modulation transfer function (MTF) (Mao *et al*. 2021). In the study presented by Wan *et al*. (2021), the field of image processing was used in part. The study sought to measure the visual perception process while exploring the neural activity stimulated by various appearances of wood surfaces in humans. Wood of three distinct colors (light, medium, and dark) was cut to uncover two types of grain (radial and tangential) and finished with three gloss options (matte, semi-gloss, and gloss). Following the projection of these digital images on the screen, a new discriminative scale was devised to assess subjective evaluations, resulting in the collection of data. Neural ERP (event-related potential) data reflecting early visual perception underwent analysis of variance and correlation analysis (Wan *et al*. 2021). A pattern recognition system was developed to identify traded Amazon timber species by Vieira *et al*. (2022). Ten different species and twenty images were used, with three polishing processes applied for each timber type. As the image recognition system used, the textural segmentation method associated with Haralick features and classified by Artificial Neural Networks (Vieira *et al.* 2022).

Gloss measurement methods play an important role in objectively assessing the degree of damage to surfaces. In particular, image processing based gloss measurement developed in the Matlab program offers an innovative approach in damage detection (Özçelik and Costa 2010; Zhong *et al*. 2023). This method provides a great advantage in detecting micro changes such as scratches, abrasion, color, and gloss on the surface by measuring the gloss levels of coated surfaces with high precision (Bishop and Chase 2023; Mouzai *et al*. 2023). In another recently proposed work, a Convolutional Neural Network (CNN) system designed using transfer learning was introduced to identify surface irregularities in finished wooden objects, including blemishes, porosity, color mismatches, cracks, and knots. Image gradients based on Canny operator are used in the model (Ragb and Nagabooshanam 2024).

This research examined the damage that occurs as a result of scrubbing various wood-based panels surfaces with domestic cleaning agents. The image analysis-based gloss evaluation method allowed the detection of such damage. Rather than using traditional scrub testers, this study employed the Image Processing Based Scrub Tester (IPBST), which was developed and produced. With the help of this device, the gloss change on the sample surfaces as a result of the scrubbing process were measured using image processing techniques on a computer connected to IPBST. The digital images taken from the sample surfaces before and after the rubbing process were analyzed using the image analysis-based gloss evaluation method developed within the MATLAB program and numerical data were obtained. After removing the backgrounds of the two images taken in the studio cabin within the IPBST, the Hue Saturation Intensity (HSI) color system was switched from the RGB color space to calculate the gloss change. HSI color space is a color model used especially in image processing and computer graphics. The HSI color space provides a closer representation of how the human eye perceives colors and therefore may be more advantageous than the RGB color space in some applications. Additionally, the HSI color space is frequently used in image processing applications to separate and manipulate colors more effectively. For example, selecting and changing a specific color, making hue and saturation adjustments, *etc*. are easier in HSI space. The *I*-channel in this color space represents the gloss, and the average gloss value of two images taken before and after the scrubbing process was calculated. This method provides fast, non-contact and detailed analysis, allowing for a more comprehensive evaluation of surface quality.

Although several studies have evaluated gloss, color change or surface roughness separately, based on a literature search, no previous study has integrated a brushing simulation system with real-time image-based gloss analysis for organic coated MDF panels. The IPBST system aims to bridge this gap by combining mechanical aging with gloss evaluation via automatic image capture and HSI model.

In order to test the accuracy of the image analysis with the requirements of TS EN ISO 2813 (2014), the BYK – Gardner Spektro Guide 45/0 device (Spectro-guide sphere gloss meter, model CD-6834, BYK-Gardner GmbH, Geretsried, Germany) was employed. The proposed image analysis-based gloss evaluation method is a candidate to emerge as a strong alternative compared to traditional glossmeter methods used in gloss testing of wood-based panels.

As a result, two different gloss measurement methods were used to evaluate the durability/performance of WTP and UV printing techniques after scrubbing with domestic cleaning agents. The gloss changes caused by the scrubbing process on coated surfaces were analyzed. How these changes differ depending on the type of coating, the types of panels, and the types of domestic cleaning agents were considered in detail.

EXPERIMENTAL

Preparation of Test Samples

Various types of medium density fiberboards (MDF) that are widely utilized in the furniture industry were employed, including 8 mm thick, first-class MDF, bright white PVC-coated MDF, pre-finished lam MDF panels, high gloss acrylic-coated MDF, and raw MDF panels. MDF panels types were chosen to reflect the diversity of materials commonly used in furniture production. Each 520 × 310 mm sample was conditioned in a chamber set at 23±2 °C and 50±3% relative humidity, as specified in TS EN 322 (1999), until achieving a stable weight and 9% to 10% moisture content. A protective coating using glossy white polyurethane, cellulosic, acrylic, and water-based lacquer paints was then applied to all raw MDF panels surfaces following ASTM D3023-98 (2017) (Fig. 1a) (Budakçı 2003; DYO 2023).

In the application of lacquer paint, paints produced by Durmus Yasar and Ogullari (DYO) company in Türkiye in 2021 were used. The wood paints used; cellulosic primer (312-1029), cellulosic topcoat (311-1033), two-component polyurethane primer (602-1420), two-component polyurethane topcoat (601-1691), two-component acrylic primer (702-1035), two-component acrylic topcoat (701-1400), one-component water-based primer (A32-1000), and two-component water-based topcoat (A25-1518) were selected. Solid matter ratios and the manufacturer's recommendations were taken into account in determining the amount of paint to be applied to the panel surfaces. Information on some application and technical properties of the paints used in the study are given in Table 1.

Two coats of primer and two coats of topcoat paint were applied to the sample panels. The amount of paint was 150 g/m^2 per coat. The amount was determined using an analytical balance with a sensitivity of 0.01 g. After the primer paint application, the samples were kept at room temperature for 24 h, and then they were sanded to achieve a smooth surface with 220-grit sandpaper. After the dust was cleaned, the topcoat paint was applied. Air pressure and spray gun tip clearance were adjusted according to the manufacturer's recommendations, and the spray gun was moved 20 to 25 cm above the sample surface parallel to the surface at the same speed. This prevented the formation of faulty layers and the application of different amounts of lacquer paint.

Table 1. Some Application and Technical Properties of the Paints Used in the Experiments

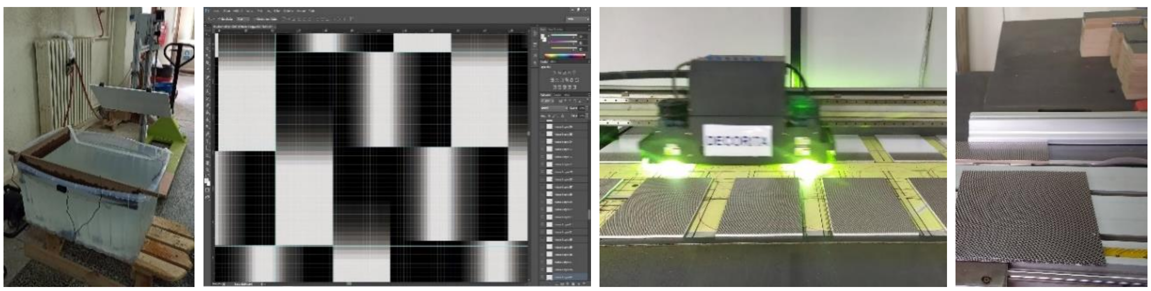
Paint Type	Solid Content (%)	Density (g/mL)	Application Viscosity (sn/DIN Cup 4 mm/20 °C)	Amount of Paint to be Applied (g/m²)	Spray Gun Tip Clearance (mm)	Air Pressure (bar)
Acrylic Primer	62	1.35	20-21	150	1.8	2-3
Acrylic Topcoat	58	1.22	19-20	150	1.8	2-3
Cellulosic Primer	56	1.20	19-20	150	1.8	3-4
Cellulosic Topcoat	38	1.24	19-20	150	1.8	3-4
Water Based Primer	48	1.22	19-20	150	1.8	2-3
Water Based Topcoat	50	1.15	18-19	150	1.8	2-3
Polyurethane Primer	75	1.50	21-22	150	1.8	2-3
Polyurethane Topcoat	66	1.32	20-21	150	1.8	2-3

The lacquered samples were initially brought to a moisture content of 9% to 10% in room conditions (Fig. 1b), followed by further conditioning within the climate-controlled chamber (Fig. 1c).

(a) (b) (c)

Fig. 1. (a) Lacquer paint application, **(b)** Setting painted samples to dry in room temperature conditions, **(c)** Preparing coated and lacquered samples under controlled conditions

Organic coating process, such as WTP and UV printing techniques, which have become more widely used recently, were treated to the surfaces of the samples. An automatic immersion device for self-pooling was designed, constructed, and utilized for the WTP techniques (Fig. 2a). A 30 μm PVAc-based WTP film featuring a carbon fiber pattern was applied to the sample panels using this device, with a 45º dipping angle, 100 cm/min speed, and dipping times between 5 and 10 s (Kaçamer and Budakçı 2023). A UV printing device, widely applied in glass coating applications, was used for the UV printing techniques. The carbon pattern design was prepared in Adobe Photoshop before the printing process (Fig. 2b) (Kurniawan and Lubis 2022). During the UV printing methods, the ink ejection head ran at a speed of 52 m/min, the UV curing lamp was configured to 1000 W Hg (mercury), and the distance from the nozzle to the sample panels surface was held at 3 mm (Fig. 2c) (Kaçamer *et al*. 2024). It is known that Hg lamps will be banned in the future according to the Minamata Convention. However, HG lamps were used in this study to reflect current industrial practices.



(a) **(b)** **(c)** **(d)**

Fig. 2. (a) WTP techniques, **(b)** Carbon fiber motif design, **(c)** UV printing techniques, **(d)** Cutting of samples

Samples used for WTP and UV printing, represent contemporary organic coatings, were cut to dimensions of 100 × 100 mm (Fig. 2d). Altogether, 840 samples were created, categorized into 84 distinct groups, each intended for two different gloss measurement methods.

Aging by Scrubbing Method

The Image Processing Based Scrub Tester (IPBST), funded by the Scientific and Technological Research Council of Turkey (TUBITAK)-221O551, was developed to evaluate how UV printed and WTP sample panels withstand domestic cleaning agents and to analyze surface gloss variations using image processing techniques (Fig. 3) (Budakçı *et al*. 2023).

To affirm the machine's precision, a calibration certificate compliant with TS EN ISO 11998:2006E was obtained from Ankara-Ostim Laboratories of the Turkish Standards Institute.

Before the scrubbing procedure, digital images of the sample panels were captured using the studio cabin attached to the machine. Subsequently, the samples were subjected to different domestic cleaning agents with the IPBST.

The household chemicals selected for the study, acetone, ethyl alcohol, dishwashing liquid, lemon juice, bleach, and cola, were chosen because they are commonly used cleaning agents in domestic environments and represent a range of chemical properties (acidic, alkaline, solvent-based). These chemicals are known to potentially interact with surface coatings, making them suitable for accelerated aging simulations. The exposure time of each chemical on the sample surfaces was standardized to match the duration of the scrubbing process, as specified in TS EN ISO 11998 and ASTM D1308-

20. Therefore, the chemical remained in contact with the surface throughout the entire scrubbing cycle. Over the course of the process, a scrubbing head unit weighing 135±1 g was used to contact the coated surfaces, following the TS EN ISO 11998 (2006) standard. A dish sponge was used as an abrasive cleaning pad. The cleaning heads executed 200 smooth linear motions along the–Z and +Z axes at a frequency of 37±2 cycles per minute. Lemon juice, ethyl alcohol, liquid dish soap, acetone, bleach, and cola were selected as the scrubbing agents based on the ASTM D1308-20 (2020) standard, by applying 5 mL of each to the surface of each individual sample (Fig. 4).

Fig. 3. The image processing-based scrub tester (IPBST)

Fig. 4. Scrubbing with acetone

Digital images of each sample were recorded before and after the scrubbing process using different domestic cleaning agents with IPBST. The overall gloss variation on the surfaces of samples treated with UV printing and WTP because of the scrubbing process was quantified using the BYK-Gardner Spektro Guide 45/0 device and the image processing-based gloss assessment technique developed in this study.

Image Processing Based on Gloss Test

The image acquisition cabin in the designed and manufactured IPBST device was designed to be closed during image acquisition so that it would not be affected by environmental conditions. The inner quadrilateral dimensions were 18x18cm, the distance between the camera and the sample was 20 cm, the cabin wall surfaces were white, and the platform where the sample to be imaged was placed was adjusted according to the dimensions of the sample on the cabin floor, and then fixed placement was achieved in each measurement. These technical arrangements were made to ensure the repeatability of our image processing technique. The highest sensitivity was achieved by ensuring that the camera saw the sample at 90º . The light intensity inside the cabin was fixed, and a 12-volt sunlight-enabled LED lamp was used. In order to avoid light reflection problems on the sample, an LED lamp of 18 cm length was placed on the ceiling and 4 sides of the cabin at equal intervals and lengths. In order to increase the accuracy of the measurement, results performed with the image processing algorithm in the proposed study, an 8 MP industrial camera and an 8 MP lens were used, and large-sized images were studied in 1440x1080 bmp format.

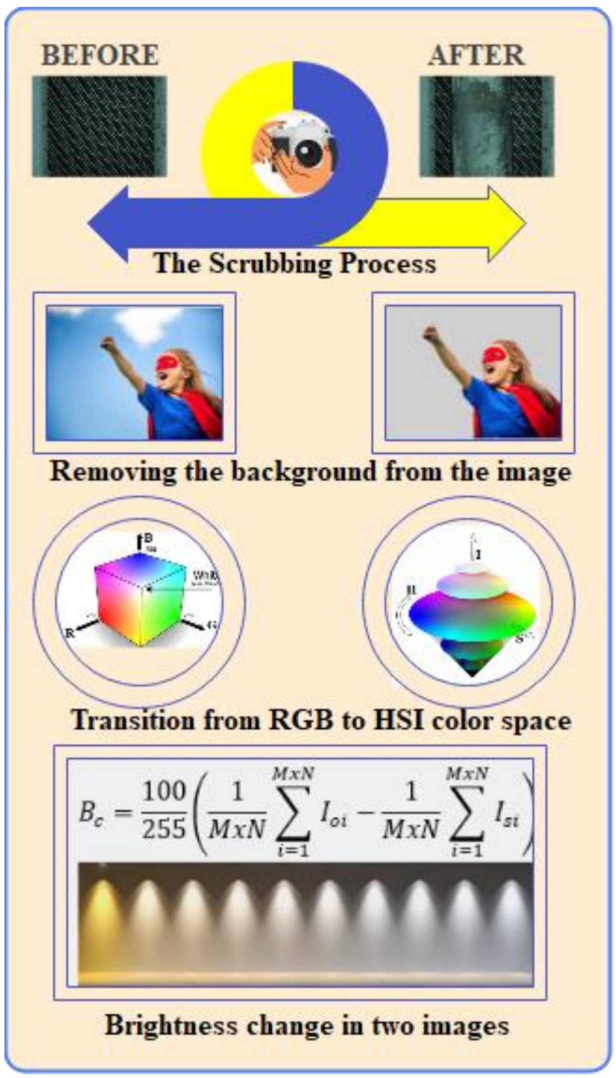


Fig. 5. Schematic representation of the steps of determining gloss change

Gloss is a perceptual and physical attribute that describes how well a surface reflects light in a specular (mirror-like) direction. It depends not only on the surface properties but also on the geometric conditions of observation and illumination. In general terms, gloss can be defined as the amount of light reflected at a specific angle compared to a standard surface under the same lighting conditions. The central aim of the study was to numerically find the amount of gloss differences between the original picture and the eroded sample picture obtained as a result of scrubbing. As seen in the flow diagram in Fig. 5, two images taken before and after the sample passed through the scrubbing process were studied. First, the backgrounds on which the sample was placed were removed to make the gloss measurement more accurate. Then, the RGB color space was switched to the HSI color system to examine the gloss states of the remaining image parts.

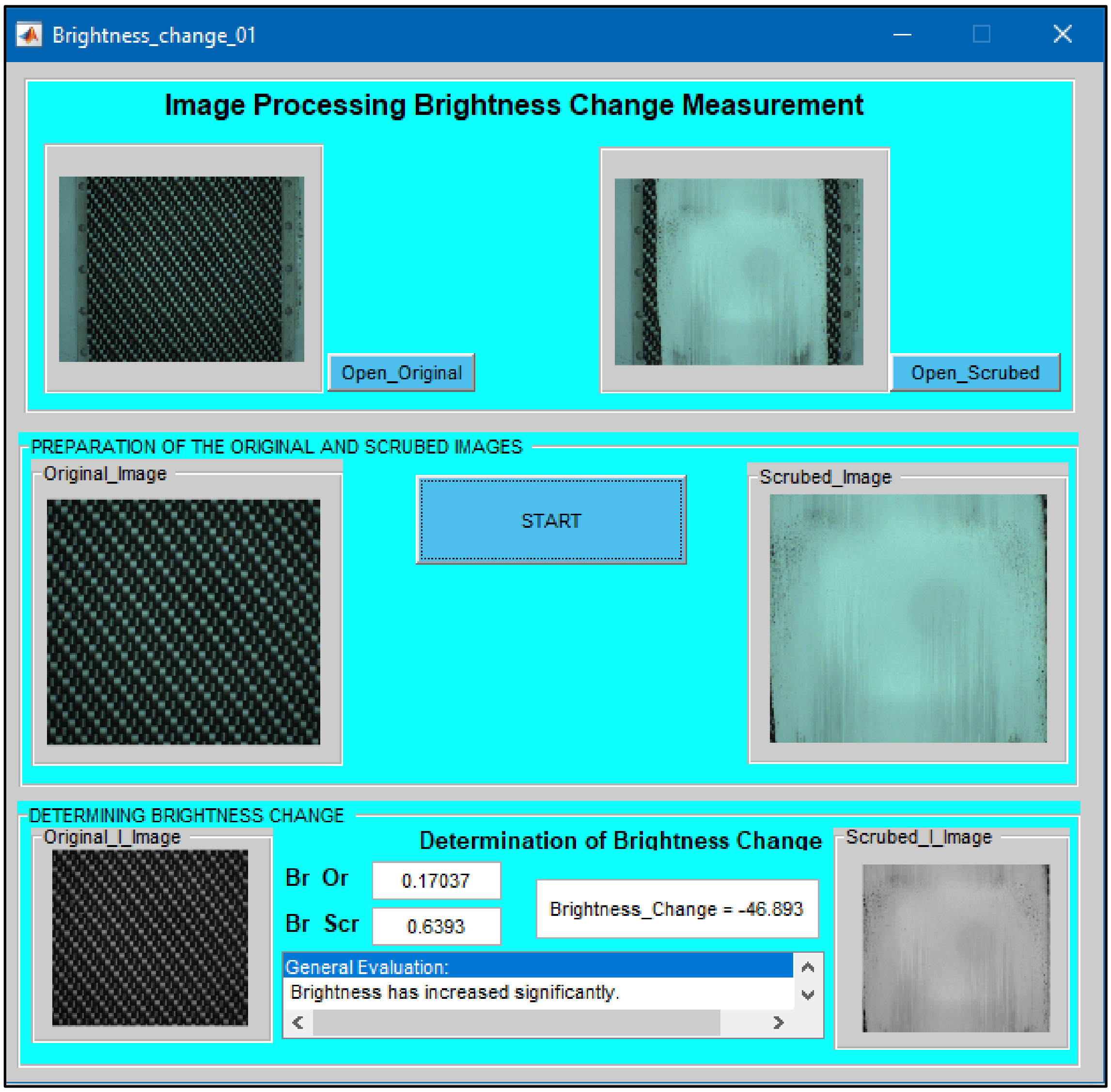


Fig. 6. Matlab GUI system for the proposed gloss change measurement using image processing

The *I* (Intensity) channel values of the HSI color space for all pixels of the images with backgrounds cut before and after scrubbing are calculated as given in Eq. 1. After finding the average value of the *I*-channel values, the difference was taken. Gloss change is presented as normalization and percentage. In Eq. 1, I_{oi} signifies the *i*-pixel value of the *I* channel before scrubbing, I_{si} signifies the *i-pixel* value of the *I*-channel of the picture particle after scrubbing, and *M* and N represent the image dimensions.

$$B_c = \frac{100}{255}\left(\frac{1}{MxN}\sum_{i=1}^{MxN} I_{oi} - \frac{1}{MxN}\sum_{i=1}^{MxN} I_{si}\right) \quad (1)$$

Gloss change *Bc* approaching zero or having a small value will mean that the gloss does not change. If the gloss is positive and large, it will be interpreted that the gloss of the sample has deteriorated (decreased) as a result of scrubbing, and if it is negative and large, it will be interpreted that the gloss has increased as a result of scrubbing. A gloss change of 100% indicates that the gloss deterioration or change is at the maximum level.

An interface has also been designed in the Matlab Graphical User Interface (GUI) software to facilitate the user in finding the gloss changes numerically. The interface view of the designed model is given in Fig. 6. Digital pictures of the samples taken prior to and following scrubbing are opened using the "Open_Original" and "Open_Scrubed" buttons in the interface environment and then the "START" button was pressed. The average gloss value before scrubbing is given as "Br Or", the average gloss value of the image after scrubbing is given as "Br Scr" and the gloss change is given as "Bc" numerically. Additionally, the status of the gloss change is presented verbally in the lower list box.

Gloss Test with BYK – Gardner Spectro Guide 45/0 Machine

Surface gloss measurements were conducted with the BYK–Gardner Spektro Guide 45/0 device to assess the test samples' resistance to domestic cleaning agents and to evaluate and compare the precision of the image processing-based gloss measurement technique (Fig. 7). Surface gloss measurements of the samples were carried out according to the principles specified in TS EN ISO 2813 (2014) using a 60º angle. Measurements were taken from the surfaces of samples that underwent UV printing and WTP after and before (control) the scrubbing process.

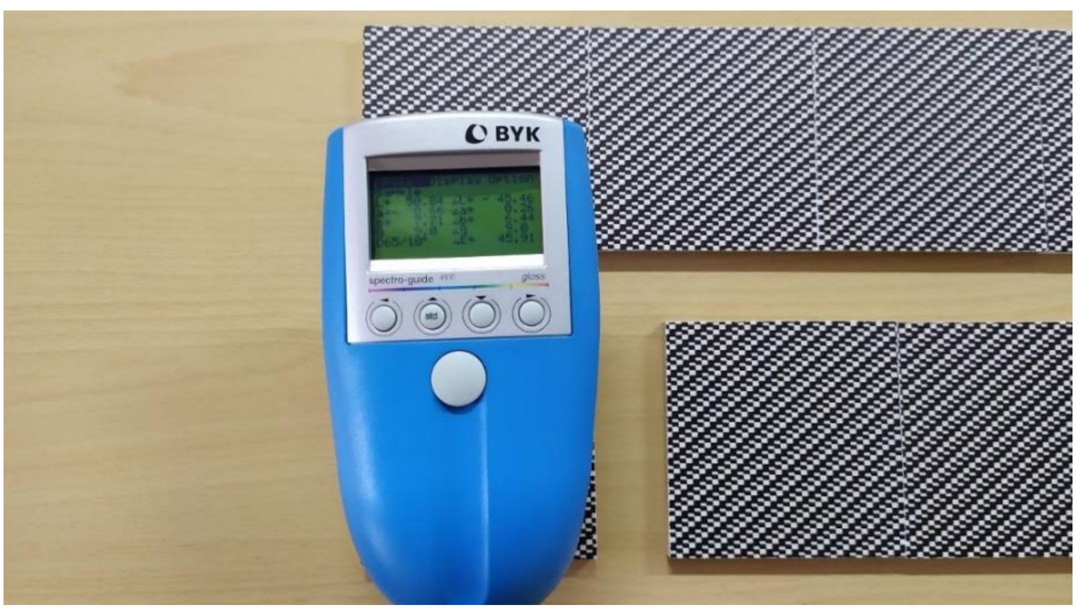


Fig. 7. Gloss measurement with BYK – gardner spectro guide device (Kaçamer 2024)

Statistical Evaluation

The data collected for this study were analyzed using the SPSS 24 (IBM Corp., Armonk, NY) and CoStat statistical software. Before the analyses, the normal distribution of values for all measured variables was confirmed with the Shapiro–Wilk's test (Shapiro and Wilk 1965). Multivariate analysis of variance (ANOVA) was employed to assess the impact of factors such as organic coating type, domestic cleaning agents' type, protective layer type, and gloss measurement method, as well as the interactions between these factors for each sample. Duncan's multiple range test (DMRT) and the least significant difference (LSD) method were utilized for comparisons, while also examining the factors responsible for observed differences. Additionally, Pearson Correlation analysis was carried out to determine the relationship between the data of the gloss test performed with IPBST and the data obtained from industrial testing devices.

RESULTS AND DISCUSSION

ANOVA Test Results

The IPBST was used to evaluate the resistance to degradation of UV-printed and WTP samples to domestic chemicals through a scrubbing process. The gloss change value observed in the coating film layer after the brushing process varied depending on the gloss measurement method, protective layer type, organic coating type, and type of domestic chemical. An Analysis of Variance (ANOVA) was conducted to identify the factors contributing to this difference. The findings are presented in Table 2.

Table 2. ANOVA Outcomes Related to Gloss Measurement Analysis

Factors	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance
Gloss Measurement Method (A)	1	1419.5190	1419.519	369.8506	0,000*
Protective Layer Type (B)	6	3278.1052	546.3509	142.3498	0.000*
Organic Coating Type (C)	1	88059.0538	88059.05	22943.47	0.000*
Domestic Chemical Type (D)	6	117130.7124	19521.79	5086.331	0.000*
Interaction (AB)	6	2117.9690	352.9949	91.97155	0.000*
Interaction (AC)	1	32207.8139	32207.81	8391.631	0.000*
Interaction (AD)	6	3098.0932	516.3489	134.5329	0.000*
Interaction (BC)	6	5489.5734	914.9289	238.3815	0.000*
Interaction (BD)	36	23895.1915	663.7553	172.9391	0.000*
Interaction (CD)	6	41677.5679	6946.261	1809.824	0.000*
Interaction (ABC)	6	2386.4265	397.7378	103.6292	0.000*
Interaction (ABD)	36	18418.1638	511.6157	133.2996	0.000*
Interaction (ACD)	6	819.6959	136.616	35.59481	0.000*
Interaction (BCD)	36	43829.4217	1217.484	317.2111	0.000*
Interaction (ABCD)	36	4250.6504	118.0736	30.76366	0.000*
Error	1764	6770.3865	3.8380876		
Total	1959	394848.3449			
Note: *Significant at 95% confidence level					

The ANOVA results indicated that all factors and their interactions significantly influenced the gloss measurement values ($P \leq 0.05$), as shown in Table 1. The outcomes of Duncan's Multiple Range Test (DMRT), conducted using the LSD critical value for the variables of gloss measurement method, type of organic coating, type of protective layer, and type of domestic chemical, are presented in Table 3.

Table 3. DMRT Findings Related to the Influences of Gloss Measurement Method, Type of Protective Layer, and Type of Domestic Chemical

Gloss Measurement Method	$\bar{x}$	***HG***	**LSD**
BYK – Gardner Spektro Guide 45/0	21.34	**A***	± 0.17
Image Processing Based Gloss Measurement (IPBST)	19.64	B	
Organic Coating Type	$\bar{x}$	***HG***	LSD
Water Transfer Printing (WTP)	27.19	**A***	± 0.17
UV Printing	13.79	B	
Protective Layer Type	$\bar{x}$	***HG***	LSD
Cellulosic Lacquer Painted	18.81	D	± 0.33
Acrylic Lacquer Painted	21.72	**A***	
Polyurethane Lacquer Painted	21.83	**A***	
MDF Lam	19.93	C	
Water Based Lacquer Painted	18.65	D	
PVC MDF	21.87	**A***	
High Gloss Acrylic MDF	20.65	B	
Domestic Chemical Type	$\bar{x}$	***HG***	LSD
Control	17.84	C	± 0.33
Acetone	39.07	**A***	
Alcohol	19.33	B	
Bleach	17.47	D	
Dishwashing Liquid	14.03	E	
Lemon juice	17.92	C	
Coke	17.81	C	
Note: $\bar{x}$: Arithmetic mean; * : The highest gloss change value; HG: homogeneity group			

Based on the data in Table 3, the highest gloss value at the measurement method level was recorded using the BYK Gardner Spektro Guide 45/0 device (21.34), and the lowest was determined in the measurements made with the IPBST (19.64). It is thought that the reason for this difference in surface gloss measurements is that the BYK Gardner Spektro Guide 45/0 device uses a 60º measurement angle during measurement, while the camera in the IPBST studio cabin uses a 90º measurement angle. Jaić and Palija (2015) demonstrated that gloss measurements are significantly influenced by the measurement angle, with notable differences observed between 20° and 60° geometries.

At the organic coating type level, the highest level of gloss was determined in samples coated using WTP (27.19), and the lowest in UV-printed samples (13.79). It is thought that the reason for the higher gloss in WTP-treated samples is due to the PVAc structure that forms the coating film structure. It has been determined that UV printing is a printing method applied directly to the panels surfaces, that the paint used in printing dries rapidly under ultraviolet rays (lamp) and therefore the roughness gives the feeling of tactileness, and as a result, the roughness in the UV printing film negatively affects the gloss (González Lazo *et al*. 2016; Marathe and Raval 2019).

At the level of protective layer type, the highest level of gloss was found in polyurethane lacquer painted MDF (21.83) samples, and the lowest in cellulosic lacquer painted MDF (18.81) samples. When the polyurethane lacquer painted sample surfaces were examined, it was observed that the coating surfaces were almost not damaged after the scrubbing process with household chemicals. This may be due to the superior layer properties of two-component polyurethane resins, such as being hard, flexible, durable, and resistant to abrasion and chemicals. It has been reported in the literature that polyurethane paint resin is combined with the reaction of isocyanate, polyol, and aliphatic urethane components. Thus, the reaction of these components provides the best compatibility with the new type of film layers applied on the paint quality and prevents the gloss status from being negatively affected by scrubbing (Metin 2017; Yilmaz *et al*. 2018). The reason why the gloss value is very low in cellulosic lacquer painted samples can be shown as the alternating structure of the cellulosic film layer. Especially after scrubbing with acetone, the WTP and UV printing film and the cellulosic lacquer paint film layer on the substrate were completely dissolved by the strong solvent effect of acetone. Therefore, low gloss values were obtained on the exposed raw MDF panels surfaces. In the literature, it is explained that cellulosic paint consists of single-component cellulose derivatives such as nitrocellulose, cellulose acetate, propionate or cellulose nitrate, and that acetone is used to dissolve this substance, and that its resistance to chemicals is not very high (Paşa 2006; Tahmasebi *et al*. 2016; Muvhiiwa *et al*. 2021).

At the domestic chemical type level, the highest level of gloss was measured in samples scrubbed with acetone (39.07), and the lowest was measured in samples scrubbed with dishwashing detergent (14.03). It is thought that this is due to the bright white structure of the protective coating on the panels surfaces that is exposed as a result of the complete abrasion of some organic coating films (WTP and UV printing) after the scrubbing process with acetone (excluding cellulosic lacquer painted samples). It can be said that there was an increase in the gloss values as a result of the measurements taken from these surfaces after the rubbing process. It is hypothesized that phosphate serves as the active component contributing to the reduced gloss values on the sample surfaces following the scrubbing process with dishwashing detergent. It has been reported in the literature that the phosphate in the dishwashing detergent component makes it easier to clean dirt and oils on material surfaces, causes the minerals on the surfaces to dissolve, and these minerals give the surfaces a matte appearance (Gambogi *et al.* 2009; Rungyuttapakorn and Wongwatcharapaiboon 2019).

The high resistance of polyurethane lacquer paint film layers to household chemicals can be attributed to their densely cross-linked polymer structures that limit chemical penetration. In contrast, cellulosic lacquer paint film layers, which are more porous and less chemically stable, are more prone to degradation under solvent exposure.

DMRT Comparative Results Acquired *via* the BYK-Gardner Spektro Guide 45/0 and the Image Analysis-Based Gloss Measurement Techniques

Table 4 presents the DMRT comparison to assess variations in gloss values among the sample groups. BYK-Gardner Spectro Guide 45/0 device and the image processing-based gloss assessment test method developed within this research were used to measure the gloss value on the sample surfaces. The data obtained by these two methods are organized according to the factors associated with protective layer type, measurement methods, domestic chemicals type, and organic coating type.

Table 4. DMRT Outcomes Related to Variations in Gloss Values Among Factors of Measurement Techniques, Organic Coating Categories, Domestic Chemical Types, and Protective Layer Variants

Protective Layer Variants	Organic Coating Categories	Domestic Chemical Type	Measurement Methods			
			Image Processing Based Gloss Measurement		BYK-Gardner Spektro Guide 45/0	
			x̄	***HG***	**x̄**	***HG***
Cellulosic Lacquer Painted Sample	WTP	Control	16.80	&i-zA	34.68	LMN
		Acetone	32.10	Q-T	1.34	**&&&h**
		Alcohol	17.48	&f-s	35.48	LM
		Bleach	16.50	&j-zAB	38.10	K
		Dishwashing	15.33	&w-zA-I	28.28	VWX
		Lemon juice	17.05	&g-v	33.57	N-Q
		Coke	17.36	&f-t	37.78	K
	UV Printing	Control	16.84	&g-x	8.92	&&&a-e
		Acetone	38.63	H	1.51	&&&h
		Alcohol	17.70	&f-q	8.97	&&Za-d
		Bleach	16.56	&i-zA	7.25	&&&ef
		Dishwashing	15.39	&v-zA-H	5.31	&&&g
		Lemon juice	16.11	&p-zA-E	8.57	&&&cde
		Coke	15.88	&s-zA-F	7.51	&&&def
Polyurethane Lacquer Painted Sample	WTP	Control	17.37	&f-t	28.72	VW
		Acetone	64.70	D	80.47	B
		Alcohol	18.13	&f-j	34.08	MNO
		Bleach	16.95	&g-x	25.33	Za
		Dishwashing	17.74	&f-q	17.87	&f-n
		Lemon juice	17.92	&f-n	32.12	Q-T
		Coke	18.00	&f-m	31.53	RST
	UV Printing	Control	16.31	&m-zA-	11.34	&&Q-V
		Acetone	16.44	&j-zAB	14.54	&&D-L
		Alcohol	16.94	&g-x	13.60	&&J-O
		Bleach	16.72	&h-y	9.51	&&W-C
		Dishwashing	14.91	&zA-L	5.86	&&&fg
		Lemon juice	16.03	&q-zA-F	10.73	&&S-Y
		Coke	15.88	&s-zA-F	11.37	&&Q-V
Acrylic Lacquer Painted Sample	WTP	Control	17.84	&f-o	32.29	P-S
		Acetone	62.59	E	68.34	C
		Alcohol	18.48	&e-g	35.99	L
		Bleach	17.63	&f-r	32.77	O-R
		Dishwashing	16.97	&g-x	18.97	&ef
		Lemon juice	18.24	&e-i	33.85	M-P
		Coke	18.06	&f-l	32.36	P-S
	UV Printing	Control	16.70	&h-y	9.52	&&W-
		Acetone	17.37	&f-t	14.81	&&B-L
		Alcohol	17.30	&f-t	10.66	&&S-Z
		Bleach	17.03	&g-w	8.75	&&&b-e
		Dishwashing	15.10	&yzA-L	6.10	&&&fg
		Lemon juice	16.33	&m-zA-	9.17	&&XYZa-
		Coke	16.27	&n-zA-C	8.65	&&&&cd
	WTP	Control	16.61	&i-z	21.53	&bcd
		Acetone	57.64	F	48.54	I
		Alcohol	17.06	&g-v	26.51	YZa
		Bleach	16.87	&g-x	20.89	&cd
		Dishwashing	16.68	&i-y	18.41	&efgh
		Lemon juice	18.10	&f-k	20.78	&cd

Water Based Lacquer Painted Sample		Coke	17.29	&f-t	22.29	&bc
	UV Printing	Control	15.91	&s-zA-F	10.96	&&R-W
		Acetone	16.38	&k-zA-C	13.59	&&K-O
		Alcohol	16.34	&l-zA-C	11.69	&&Q-T
		Bleach	16.15	&o-zA-E	9.79	&&U-
		Dishwashing	14.48	&&E-L	6.29	&&&fg
		Lemon juice	15.32	&w-zA-I	10.40	&&T-Zab
		Coke	15.70	&t-zA-G	10.10	&&T-
MDF Lam Sample	WTP	Control	15.92	&r-zA-F	22.84	&b
		Acetone	55.78	G	92.94	**A***
		Alcohol	16.61	&i-z	26.77	XYZ
		Bleach	16.30	&m-zA-	22.97	&b
		Dishwashing	15.95	&r-zA-F	17.40	&f-t
		Lemon juice	16.90	&g-x	22.91	&b
		Coke	16.40	&k-zAB	25.04	&a
	UV Printing	Control	14.07	&&G-N	11.78	&&P-T
		Acetone	14.87	&&A-L	14.79	&&B-L
		Alcohol	14.34	&&F-M	12.30	&&O-S
		Bleach	13.94	&&H-O	9.70	&&V-
		Dishwashing	12.76	&&M-Q	6.41	&&&fg
		Lemon juice	13.49	&&L-P	10.86	&&R-X
		Coke	13.63	&&I-O	10.50	&&T-Za
High Gloss Acrylic MDF Sample	WTP	Control	16.06	&q-zA-E	27.74	WXY
		Acetone	59.14	F	81.94	B
		Alcohol	17.29	&f-t	27.67	WXY
		Bleach	15.97	&r-zA-F	27.98	VWXY
		Dishwashing	16.22	&n-zA-D	19.91	&de
		Lemon juice	16.40	&k-zAB	28.09	V-Y
		Coke	16.15	&o-zA-E	26.89	XYZ
	UV Printing	Control	14.89	&zA-L	11.13	&&Q-W
		Acetone	16.10	&q-zA-E	16.26	&n-zABC
		Alcohol	15.46	&u-zA-H	12.57	&&N-R
		Bleach	15.04	&yzA-L	9.11	&&YZa-d
		Dishwashing	13.83	&&H-O	6.78	&&&fg
		Lemon juice	14.68	&&C-L	10.78	&&S-Y
		Coke	14.46	&&E-M	9.75	&&V-
PVC MDF Sample	WTP	Control	16.08	&q-zA-E	30.65	STU
		Acetone	53.60	H	38.94	K
		Alcohol	17.19	&g-t	30.54	TU
		Bleach	16.30	&m-zA-	30.57	TU
		Dishwashing	11.48	&&Q-U	17.83	&f-p
		Lemon juice	17.15	&g-u	30.87	STU
		Coke	16.23	&n-zA-D	29.68	UV
	UV Printing	Control	15.27	&x-zA-K	10.87	&&R-X
		Acetone	58.33	F	42.29	J
		Alcohol	21.96	&bc	12.23	&&O-S
		Bleach	15.31	&w-zA-J	9.12	&&YZa-d
		Dishwashing	13.81	&&H-O	6.64	&&&fg
		Lemon juice	14.91	&&zA-L	10.37	&&T-Zab
		Coke	14.86	&&A-L	9.18	&&X-Za-
LSD ± 1.72						
*Note: $\bar{x}$: Arithmetic mean; * :the highest gloss change value; HG: homogeneity group*						

Table 4 indicates that the samples achieved the highest gloss measurement (92.94) on which acetone was scrubbed after WTP was applied to MDF Lam surfaces in the measurements made using the BYK Gardner Spectro Guide 45/0 device. Following the acetone scrubbing process, the water transfer printing (WTP) coating layer applied on the surface of the MDF Lam panels was completely removed due to its low resistance to the solvent. However, the underlying laminated surface of the MDF Lam panel exhibited high chemical resistance and remained largely intact despite the aggressive nature of the acetone solution. As a result, the gloss measurements taken after scrubbing reflected the properties of the original laminated substrate rather than the WTP coating. This condition explains the relatively high gloss values recorded in the MDF Lam group after acetone treatment.

The samples processed with acetone scrubbing after applying WTP on cellulosic lacquered MDF showed the lowest gloss measurement (1.34) according to the BYK Gardner Spectro Guide 45/0 results.

(a) **(b)**

Fig. 8. (a) Sample treated with acetone scrubbing following WTP application on the cellulosic lacquer-coated MDF surface, **(b)** Sample treated with acetone scrubbing following WTP application on the MDF Lam surface

The study identified the lowest gloss measurement on cellulosic lacquered sample surfaces following acetone scrubbing (Fig. 8a). This situation is due to the fact that the acetone chemical completely dissolves the organic coating films (WTP and UV printing) and cellulosic lacquer painted surfaces, thus negatively affecting the gloss of the exposed raw MDF panels surfaces. It was understood that the gloss value increased in the sample group because the laminated layer on the surface of the panels preserved its gloss value almost without any deterioration after the WTP on the MDF Lam surface was completely eroded by acetone (Fig. 8b).

After water transfer printing was applied to the surfaces of MDF board type panels with protective layer, the scrubbing process with acetone chemical caused all coatings on the wtp coated surfaces to wear off. This situation showed that the coating structure of WTP was not suitable for cleaning with acetone. When MDF type panels with ultraviolet printing application were scrubbed with acetone, cellulosic lacquer painted MDF and PVC MDF sample surfaces were completely worn off. This situation showed that cellulosic lacquer painted MDF panels and PVC MDF panels were not suitable for coating with WTP and UV printing and also for cleaning with acetone (Table 4).

The main reason for the increase in the gloss values of the samples rubbed with acetone is the complete abrasion of the coating film made with the WTP or UV printing technique from the panel surfaces and the resistance of the protective layers on the MDF board surface under these abraded layers to acetone.

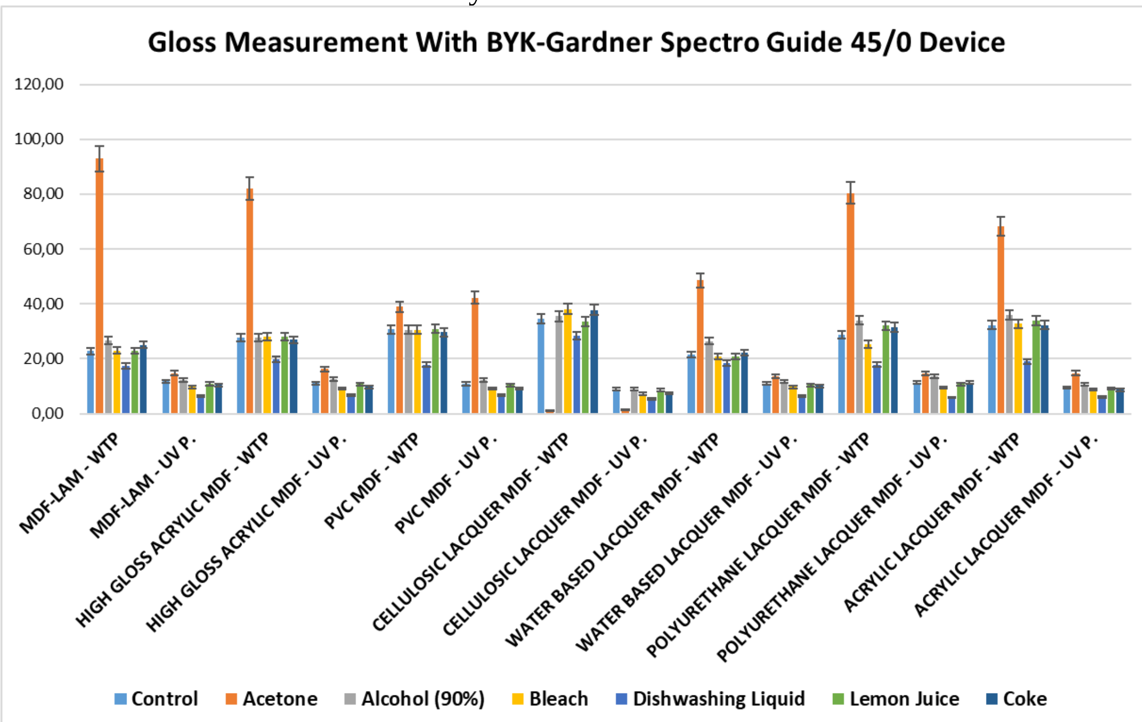


Fig. 9.a. Gloss measurement with BYK-Gardner Spectro Guide 45/0 device

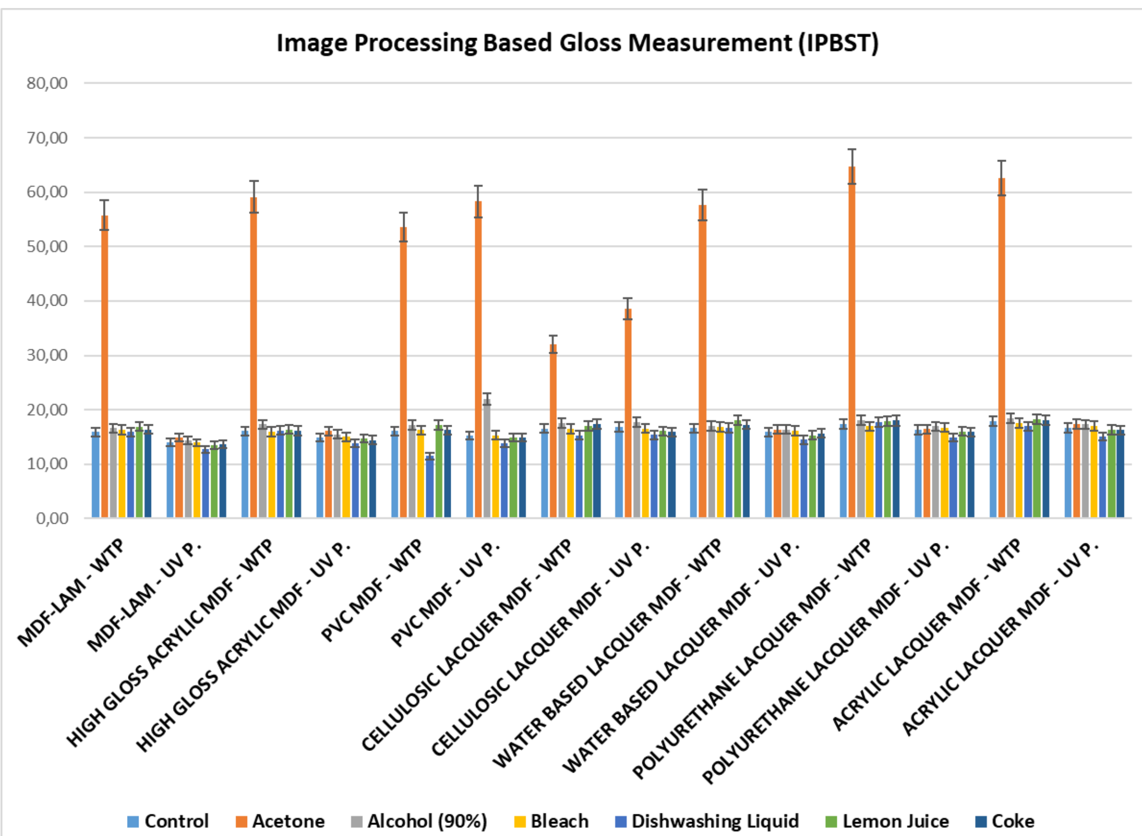


Fig. 9.b. Image processing based gloss measurement (IPBST)

When comparing the gloss data from the BYK-Gardner Spectro Guide 45/0 device and the image processing-based method, a strong agreement was observed for the highest and lowest gloss values of samples treated with domestic cleaners (Fig. 9.a.b).

Correlation Analysis of Gloss Evaluation Methods

To examine the correlation between the gloss values obtained using the BYK-Gardner Spectro Guide 45/0 and the image processing-based gloss measurement method, a Pearson correlation analysis was performed. This analysis focused on the gloss changes observed after scrubbing the WTP-coated sample surfaces with domestic cleaning agents. The results of the analysis are provided in Table 5.

Table 5. Correlation between the BYK-Gardner Spectro Guide 45/0 and the Image Processing-Based Gloss Measurement Technique

Sample Measurement Amount (n)	Pearson Correlation Coefficient (r)	P-Value
1680	0.71	0.000*

*: Significant at $P < 0.01$

As indicated in Table 5, the results of the Pearson correlation analysis revealed a robust and statistically significant positive correlation of 0.71 between the two distinct gloss measurement techniques. This correlation is illustrated in Fig. 10.

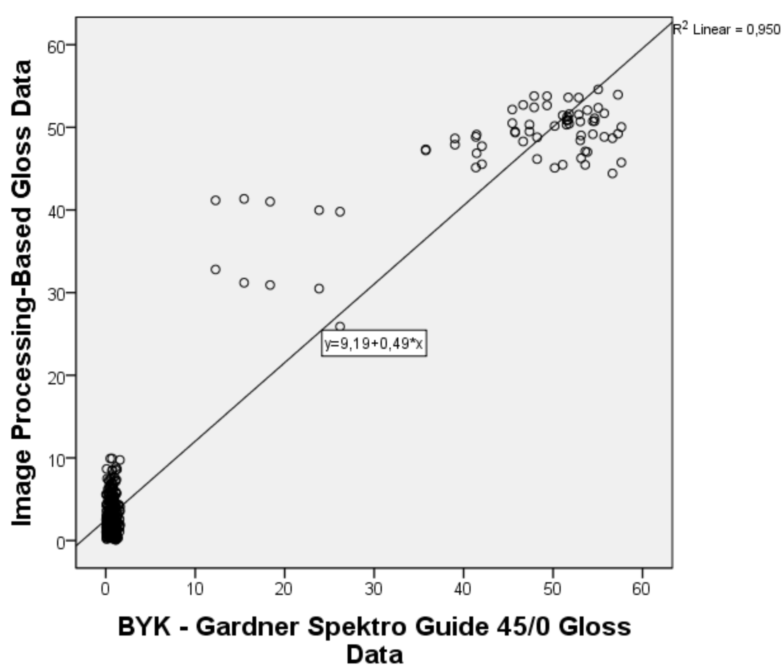


Fig. 10. Relationship between the results derived from two distinct gloss measurement techniques.

The correlation plot presented in Fig. 10 illustrates that the data derived from the image processing-based gloss measurement techniques could serve as a viable substitute for the BYK- Gardner Spectro Guide 45/0 device.

CONCLUSIONS

1. It has been established that the image processing-based gloss measurement technique presents a viable alternative to conventional industrial testing instruments. Notably, the robust correlation coefficient (+0.71) further reinforces the accuracy and dependability of this method. The demo software associated with the proposed image processing-based gloss measurement approach facilitates broader and international adoption, potentially enabling standardization and enhancing cost efficiency within the industry.
2. The highest gloss values were obtained using the BYK Gardner Spektro Guide 45/0, whereas the lowest gloss values were recorded using the image processing-based gloss measurement technique.
3. The image processing technique for gloss measurement was found to be three times faster compared to the BYK-Gardner Spectro Guide 45/0 device. Image processing-based gloss measurement, which emerges as a practical and innovative alternative, shows that it will provide a significant advantage for researchers and the paint/coating industry.
4. It was observed that the WTP or UV printing film on polyurethane lacquered MDF surfaces was not damaged after scrubbing with domestic cleaning agents. Therefore, it is thought that the WTP or UV printing film on the polyurethane lacquer paint surface provided good bonding compatibility.
5. Low gloss values were obtained after scrubbing with acetone on cellulosic lacquer painted surfaces. The WTP or UV printing film on the cellulosic lacquer paint surface has been observed to have very low resistance performance against household cleaning agents. Therefore, it is thought that the WTP or UV printing film on the cellulosic lacquer paint surface does not provide good bonding compatibility.
6. Samples with WTP showed higher gloss compared to samples coated with UV printing. WTP can be preferred in organic applications requiring high gloss. UV printing may be more suitable for applications requiring a matte surface.
7. Overall, the samples coated with polyurethane or acrylic lacquer demonstrated superior resistance to household cleaning agents, whereas those finished with cellulosic or water-based lacquer exhibited lower resistance. Moreover, MDF Lam samples and high-gloss acrylic-coated MDF displayed better durability against domestic cleaning agents compared to PVC-coated MDF samples.
8. It has been observed that acetone destroys the coating films on panels surfaces, while dishwashing detergent provides a matte appearance on the coating surfaces. It is recommended not to use both chemicals when cleaning coated furniture surfaces.
9. The solvent property of acetone can be used positively for panels coated with WTP and UV printing techniques. For example, instead of reproducing the defective coated panels during production, by rubbing them with acetone, the coating films on their surfaces can be cleaned without scraping. Thanks to the easy cleaning of the coating from the panels surface, reprinting on the same panels surface will reduce costs and labor services.

In the woodworking industry or the furniture sector, it is recommended to choose polyurethane paint that is highly resistant to domestic chemicals. For example, since kitchen and bathroom furniture are frequently exposed to chemical solutions, it is recommended to coat the wooden panels that make up the furniture with polyurethane paint.

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