INFLUENCE OF MACHINED SURFACE SHAPE ON LIGHT ABSORPTION

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There are different factors that have influence on light absorption of a given material, e.g. material colour and thickness, angle of light incidence, surface shape, roughness, porosity and surface cleanliness. This paper is focused on material ability to absorb light. For this reason, different surface shapes of a polyvinylchloride material were produced on CNC milling machine. There were investigated the effect of width, depth and number of differently shaped grooves on light absorption in this paper. It was found in this study that the effect of the surface shape has a significant influence on light absorption. This fact was verified by a computer simulation, which was performed using Wdls 4.1 software.

KEYWORDS

CNC machining, surface shape, light absorbance groove, illuminance, computer simulation.

1. INTRODUCTION

Our environment is connected with different environmental factors, e. g. with thermal comfort, air and water pollution, light conditions, mechanical vibration [Olejarova 2016, Cizikova 2016] and acoustic phenomena. These factors have a significant influence on psychic comfort, health, labour protection, manufacturing accuracy etc.

This paper is focused on the investigation of surface shape of a polyvinylchloride material on its ability to absorb light. The investigation of light absorption properties was performed on differently shaped polyvinylchloride samples under diffuse daylight and was subsequently verified using Wdls 4.1 software.

2. METHODOLOGY

In case of the tested non-transparent polyvinylchloride (PVC) material, the incident luminous flux f_i consists of the reflected luminous flux f_r and the absorbed luminous flux f_a. The light absorption is given by the material ability to absorb incident light [Ramus 1978] and is expressed by the absorbance α as follows [Schreuder 2008, Whiffen 2013]:

$$\alpha = \frac{\phi_a}{\phi_i} \tag{1}$$

The light absorption of materials depends in general on many parameters, e. g. on material thickness, angle of light incidence, surface shape, roughness, porosity, density, spectral composition of radiation, surface cleanliness etc.

Similarly, the reflectance β is given by the ratio of the reflected luminous flux f_r to the incident luminous flux f_i:

$$\beta = \frac{\phi_r}{\phi_i} \tag{2}$$

The interrelationship between the absorbance α and the reflectance β for non-transparent materials is evident from the law of energy conservation:

$$\alpha + \beta = 1 \tag{3}$$

The absorbance α was determined from the above-mentioned equation on the basis of the reflectance β, which was obtained by means of the illuminance ratio [Slezak 2006]:

$$\beta = \frac{E_r}{E_i}\ , \tag{4}$$

where: E_r – reflected illuminance from material surface, E_i – incident illuminance on material surface.

Figure 1. Digital illuminometer Voltcraft MS-1300

The illuminances were experimentally measured hundred times by means of the digital illuminometer Voltcraft MS-1300 (see Fig. 1) for each sample. It was subsequently possible to obtain hundred values of the absorbance (i.e. $\alpha_1, \alpha_2, \ldots, \alpha_{100}$). An average value of the absorbance was subsequently determined from the equation:

$$\alpha = \frac{\sum_{i=1}^{100} \alpha_i}{100} \tag{5}$$

The percentage daylight factor DF (%) is the most common parameter to characterize the annual daylight availability in buildings. It is proportional to the ratio of the indoor illuminance E_x in a point x on investigated working surface to the outdoor diffuse illuminance E_h on horizontal surface [Calcagni 2004, Reinhart 2000]:

$$DF = \frac{E_x}{E_h} \cdot 100 \tag{6}$$

For sample preparation was used CNC milling machine tool HWT C-442, designed for machining easy-to-machine materials, such as aluminium alloys, graphite and plastics. The tool path was controlled by instructions of the part program. This program for the machine was created in NX 9.0 using Planar Mill operations for machining along the curve. This solution allows compliance to the required groove quality with corresponding accuracy [Dovica 2016, Holesovsky 2014, Matras 2014].

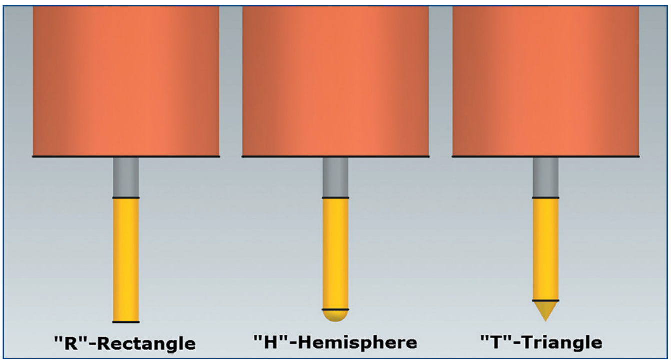

Figure 2. Tool shape and groove description

Appropriate cutting tools were selected for groove shapes. Grooves with a rectangular cross-section were created by a sharp end mill without corner radius SECO 93030 of the diameter D = 3 mm and the cutter SECO 512060Z2.0-Siron-A with the diameter of 6 mm. The cutting tool SECO 29040 was used to produce the grooves of the triangle shape, next the cutting tool SECO 97062 created a hemisphere-shaped grooves. Shapes and description of the cutting tools are shown in Fig. 2.

Samples with grooves on the surface for light absorption measurements were not only made varying the shapes, but also with different geometric parameters. According to the specification in the Fig. 3, grooves were made in three different pitches p = 48, 24, 12 mm with the groove depths of d = 3 and 6 mm. The rectangle grooves were kept parallel to the X axis (identified as RX) and were used to compare in two directions X and Y (identified as RXY).

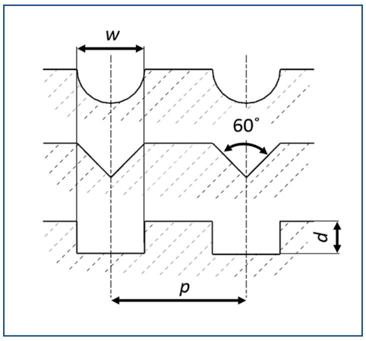

Figure 3. Groove specification

Samples for light absorption measurements were made from plastic sheets based on expanded PVC with homogeneous light and colour properties in all layers. The technical characteristics of this material are listed in Tab. 1.

Property	Method	Value	
Density	D-792	0.52–0.55	$[g/cm^3]$
Water absorption	D-570	0.28	[%]
Flexural modulus	D-790	700–1100	[MPa]
Hardness	Shore D	78–84	[ShoreD]
Izod impact strength	D-265	30–66	[J/m]
Service temperature range		–10 to 55	[°C]
Heat deflection temperature	D-648	58–61	[°C]
Vicat softening temperature	D-1525	75–77	[°C]
Coefficient of linear thermal expansion	D-696	6.7x10–5	[cm/cm°C]
Thermal conductivity	C-177	0.07	[W/mK]
Surface resistance	D-257	5x1015	[Ohm]
Volume resistance	D-257	2x1016	[Ohm-cm]

Table 1. Technical data of the investigated plastic material

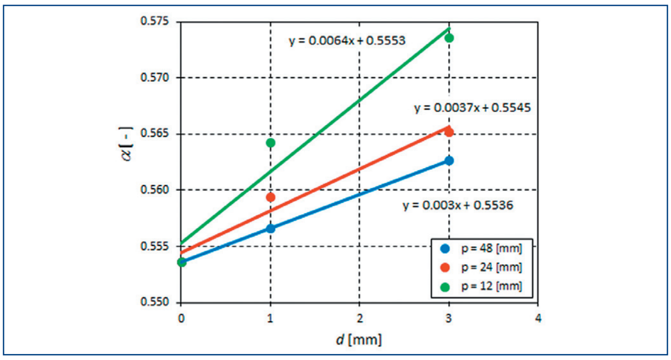

Figure 4. Effect of rectangular groove depth on light absorbance for different groove pitches and the groove width w = 3 mm

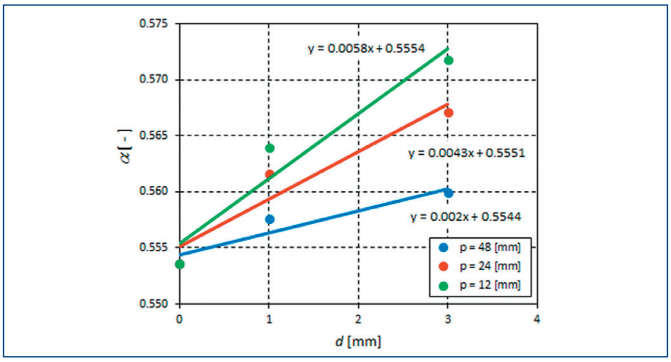

Figure 5. Effect of rectangular groove depth on light absorbance for different groove pitches and the groove width w = 6 mm

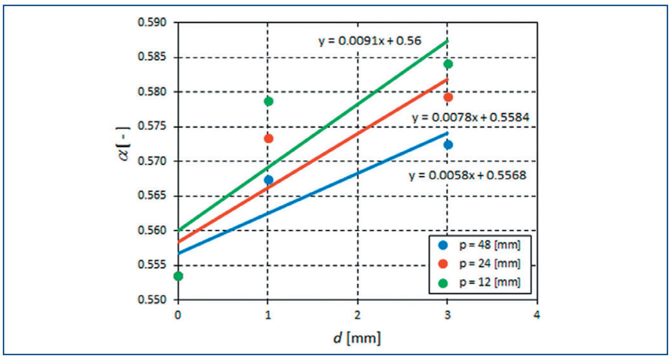

Figure 6. Effect of rectangular groove depth on light absorbance for different groove pitches in two directions and the groove width w = 6 mm

3. MEASURED DEPENDENCIES OF LIGHT ABSORBANCE

There is evaluated the effect of different parameters on light absorption in this chapter. Firstly the light absorbance a = 0.5536 was experimentally determined for the smooth polyvinylchloride sample. The light absorbances of the profiled surface samples were subsequently measured and evaluated too.

The influence of the groove depth on the light absorbance is evident from Fig. 4 ÷ Fig. 6. It is evaluated for the rectangular grooves of two different widths (i.e. 3 mm and 6 mm) and three different pitches between neighboring grooves. The absorbance was also evaluated for the grooves that were produced in two mutually perpendicular directions (see Fig. 6). It is evident that the groove depth has a significant influence on the light absorption. The absorbance is in general increasing with increasing the groove depth. It was also found that the absorbance is increasing with decreasing the groove pitch. The above-mentioned facts were caused mainly by multiple light reflections and a larger absorption area in comparison with the smooth polyvinylchloride surface.

The influence of number of groove directions on the light absorbance is shown in Fig. 7. The comparison is performed for the rectangular grooves of the width w = 6 mm and two different depths (i.e. for 1 mm and 3 mm) and for different groove pitches. It was found that higher values of the light absorbance were obtained for the grooves that were produced in two perpendicular directions, i.e. in case of the double number of the rectangular grooves. Furthermore, the light absorbance is in general decreasing with increasing the groove pitch.

The effect of the groove shape on light absorption is shown in Fig. 8. The comparison is performed for the grooves of the width w = 6 mm and the depth d = 3 mm. It is evident that the highest material ability to absorb light was obtained in the case of the triangular grooves. On the contrary, the lowest light absorbance was found for the rectangular grooves.

The effect of the rectangular groove width on the light absorbance is shown in Fig. 9. It is evident that the light absorbance is in general increasing with increasing the groove width.

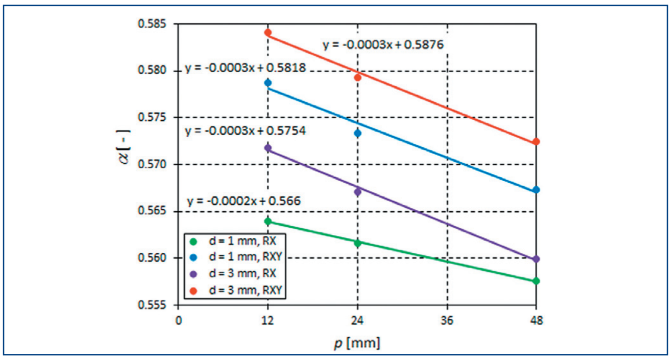

Figure 7. Effect of groove pitch on light absorbance for different number of directions

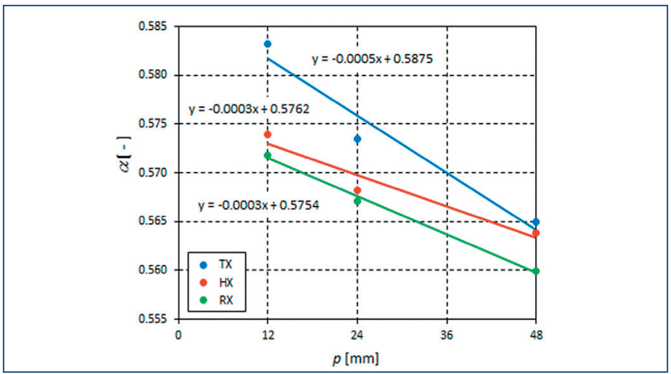

Figure 8. Effect of groove shape on light absorbance (w = 6 mm, d = 3 mm)

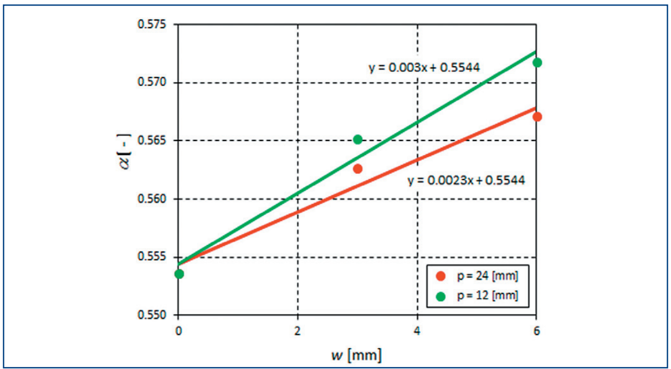

Figure 9. Effect of groove width on light absorbance (d = 3 mm)

4. SIMULATION OF INFLUENCE OF SURFACE SHAPE ON LIGHT ABSORPTION

Mathematical simulations of the percentage daylight factor *DF* were performed using Wdls 4.1 software (Astra 92 a. s. Zlín, Czech Republic) on the basis of multiple reflections of the incident light. These simulations were obtained in a reference room (see Fig. 10) of the grand plane size 5 m × 4 m and the height h = 2.8 m. The room also consists of a door (1.6 m × 2 m) and a window (2 × 1.5 m), which is located in the height h = 1 m above the room floor and has the light transmittance t = 0.92. The light reflectances r of different room surfaces are shown in Table 2.

Room surface	ρ [–]
Walls	0.45
Ceiling	0.70
Floor	0.30
Door	0.15
Window	0.05

Table 2. Light reflectance of different room surfaces in the investigated room

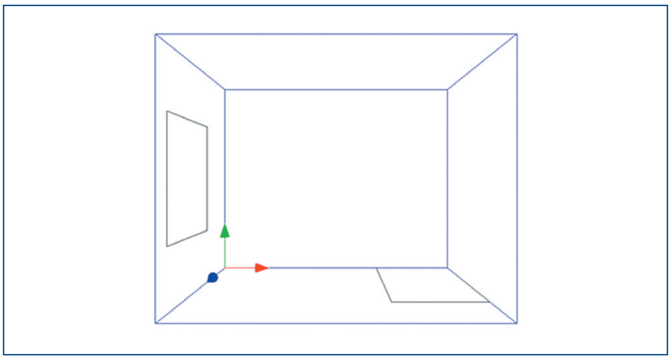

Figure 10. Investigated reference room

There aren´t supposed artificial luminous sources in the investigated room (see Fig. 10). The horizontal working plane in the height h = 0.85 m above the room floor was used to evaluate the daylight factor distribution. There is also supposed the same roughness (i.e. the same reflectance) of the smooth walls and the groove surfaces in these simulations.

The simulated values of the daylight factor in computing points on the horizontal working plane of the investigated room with smooth walls are shown in Fig. 11. It is evident that the highest values of the daylight factor are obtained in the place of daylight entrance into the room (i.e. at the window). The daylight factor is in general decreasing with increasing the distance from the window. The minimum value DF_{min} = 1.36 % is obtained at the door of the room. It is given by the lower value of the door reflectance compared to the wall reflectance.

The effect of rectangular grooves (i.e. of the type X) in the room walls on the daylight factor distribution is demonstrated in Fig. 12 and Fig. 13. Fig. 12 shows the simulation of the daylight factor distribution for

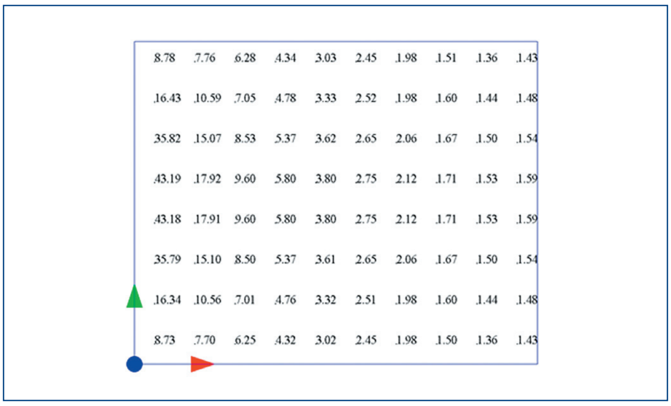

Figure 11. Daylight factor distribution in computing points for the room with smooth walls

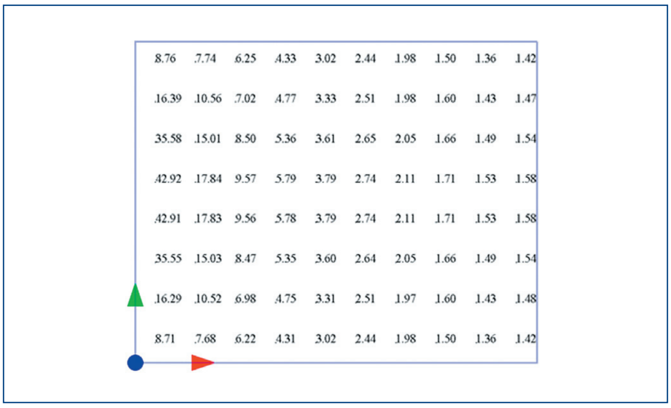

Figure 12. Daylight factor distribution in computing points for room with rectangular groves of the type X (w = 6 mm, d = 3 mm, p = 12.5 mm)

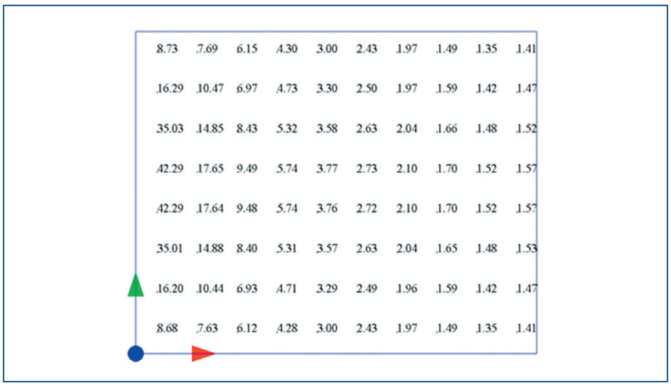

Figure 13. Daylight factor distribution in computing points for room with rectangular groves of the type X (w = 6 mm, d = 10 mm, p = 50 mm)

the rectangular grooves with the weight $w = 6$ mm, the depth $d = 3$ mm and the pitch $p = 12.5$ mm between the neighbouring grooves. Similarly, the daylight factor distribution for the rectangular grooves with the weight $w = 6$ mm, the depth $d = 10$ mm and the pitch $p = 12.5$ mm is shown in Fig. 13. It is evident that the values of the daylight factor are in general lower compared to the room with the smooth walls. It is visible mainly near the window. It is caused by multiple reflections of the incident light in the rectangular grooves. For this reason the light absorbance of the shaped surfaces is higher compared to the smooth surfaces of the walls.

5. CONCLUSIONS

The aim of this work was to investigate the influence of the surface shape on light absorption. The investigation was performed on a polyvinylchloride material with different shapes, depths, widths and pitches of grooves. It can be concluded that the minimum light absorbance was obtained in case of the smooth material surface. Higher values of the absorbance were observed in case of the profiled surfaces. It is caused by larger absorption areas, multiple incident light reflections and surface quality after machining process. The light absorbance is in general increasing with increasing the groove size and with decreasing the groove pitch. Therefore the groove shape is significant in terms of material ability to absorb light. These facts were also verified by mathematical simulations of the daylight factor distribution that were performed for differently shaped surfaces by means of Wdls 4.1 software.

The obtained facts are applicable in many cases. Rooms are equipped with profiled and perforated plates at the present time. It has a negative influence on the light reflection, e. g. in lecture and social rooms, galleries etc. Therefore the room illumination is reduced due to differently shaped profiles. For this reason, it is necessary to apply more powerful artificial light sources for certain human activities. It results in increased operating costs in order to reach normalized illumination values. On the contrary, shaped plates are suitable in rooms with lower light reflections, e. g. in cinemas, photo studios and laboratories. The illumination quality belongs to important environmental factors of human society, which must be taken into account during building projection.

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