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Research of formation of Braille element height on Chromolux cardboard

Keywords: *Braille typeface, element height, pressure effort, cardboard, analytic dependencies, method of least squares*

In the production of printed materials, informational materials for the blind, Braille packages, the main task is to ensure the reliability of reading the information by the blind. One of the most important parameters for ensuring the reliability of Braille reading is the height of its elements. When manufacturing products for the blind using a variety of materials, in this case, from cardboard, it is important to provide the conditions for conducting the technological process to obtain the required height of the Braille elements. To do this, we need to conduct the research to determine the patterns of the formation of the Braille typeface on the appropriate kind of cardboard and their mathematical description.

The analysis of recent studies, publications [1-12], current legal documents (Directives, technological conditions, technological instructions, decrees, orders, regulations) from different countries of the world regarding the requirements for the Braille typeface and its application [13-26] indicates that the technological processes of applying the Braille typeface should provide the necessary height of its elements, which directly affects the reliability of reading the information and operational parameters.

The aim of the paper is to conduct a study and describe mathematically the dependency of the height of the Braille elements on the technological parameters of Chromolux cardboard and the pressure effort.

For the study, Chromolux cardboard (Germany) has been chosen – a high gloss coated cardboard, made by the method of discharge on a heated chrome-plated cylinder, which has mirror smoothness (Table 1). As a result, a mirror gloss is formed on the surface of the cardboard. The cardboard consists of 2-4 cellulose layers of one-sided coating.

For the study of technological efforts at a different height of Braille element, which arise during the formation of a relief image on the surface of the cardboard as a result of congreve stamping, a device that has an electromechanical drive and allows a simultaneous recording of the stamping effort and the movement of the counter-stamp at a given cyclicity of the device has been used. The movement during the study was not recorded, but only the stamping efforts were recorded. The stamping effort of the slider is written in the form of charts with the help of a uni-

Table 1. Technical characteristics of Chromolux cardboard

weight, g/m^2	volume, cm^3/g	Roughness according to Taber (15°), μm		Tensile strength, mN/m	
		Transverse direction	Machine direction	Transverse direction	Machine direction
250 ± 5%	1.15	80	170	7.8	17
tolerance:		whiteness ISO 2470 (R457) – 92% ± 2 gloss ISO 8254-2 - 97% ± 3 relative humidity 50% ± 5 ref. TAPPI 502-98			

versal high-speed eight-channel analogue-to-digital converter. It is a versatile measuring device and it can be used as an oscilloscope, a recorder and a spectrum analyser.

According to the results of the experimental studies, we form the linear and nonlinear dependency of the pressure p on the height h using the method of least squares (MLS) (Table 2, Table 3) [27].

Table 2. Results of the determination of technological efforts of Chromolux cardboard

№	height h, mm	pressure p, MPa	surface mass ms, kg/m^2	thickness z, mm	volumetric density ρ, g/cm^3
1	0.289	0.283			
2	0.313	0.337			
3	0.347	0.445			
4	0.394	0.85	m_s= 0.250	z = 0.29	ρ = 0.73
5	0.612	1.633			
6	0.648	1.956			
7	0.679	2.712			

From uneven intervals in h as in Table 2, a transition to an even table in h ⇒ Table 3 is made, where the step is **Δh = 0.087 mm**.

Consequently, 0.592 = 0.679–0.087; 0.505 = 0.639–0.087, etc. 0.331 = 0.418––0.087. Pressures p_k are found by the method of linear extrapolation.

p_{k7} = 2.712 MPa – we take the same as in Table 2.

Table 3. Results of the determination of technological efforts of Chromolux cardboard (evenly spaced height with a step Δh = 0,087 mm)

№	height h, mm	pressure p, MPa	surface mass ms, kg/m²	thickness z, mm	volumetric density ρ, g/cm³
3	0.331	0.394			
4	0.418	0.643			
5	0.505	1.249	m_s= 0.250	z = 0.29	ρ = 0.73
6	0.592	1.454			
7	0.679	2.712			

Table 4
Dependency of Braille typeface height on pressure (p_k)

№	height h	pressure p_k
5	0.612	1.633
	0.592	
6	0.648	1.956

Pressure p_k for h = 0.592 mm is within [0.612; 0.648].
0.648 – 0.612 = 0.036 (mm). 0.648 – 0.592 = 0.056 (mm).
1.956 – 1.633 = 0.323 (MPa).

We make a proportion:

0.036	0.323
0.056	p_{k6}

From the proportion: $\Delta p_{r6} = \dfrac{0.056 \cdot 0.323}{0.036} = 0.502$.

$p_{k6} = 1.956 - \Delta p_{k6} = 1.956 - 0.502 = 1.454$ (MPa). Similarly, we find other p_k. Other p_k are put in the table below. Also, we put numbers in the column to the left (red digits).

Table 5. Calculated values of pressures (p_k)

n	pressure p_k. MPa
1	0.394
2	0.643
3	1.249
4	1.454
5	2.712

According to the written computer application of the method of least squares (MLS) and based on the data for p_k, we find the linear dependency of the type $p(h) = a + b \times n$ between the pressure p and the number n (in the column on the left), to which the set of values corresponds: 1, 2, 3, 4, 5: $p = a + b \times n = -0.3437 + \mathbf{0.5447} \times n$ for Table 2 (for linear dependency).

According to the method of least squares (MLS) we calculate the values in Table 6 and the corresponding formula: $p = a + b \times \mathbf{n} = -0.3437 + \mathbf{0.5447} \times n$:

Table 6. Dependency of Braille typeface height on pressure (p_n)

n	height h, mm	p_n, MPa
1	0.331	0.201
2	0.418	0.7457
3	0.505	1.29
4	0.592	1.835
5	0.679	2.379

Thus, the first intermediate result (a linear formula between the pressure and the number n), obtained using the method of least squares (MLS):

$p = p_n = a_2 + b_2 \times n = -0.3437 + \mathbf{0.5447} \times n$ (for Table 2).

First intermediate numerical result: $b_{24} = \mathbf{0.5447}$.

At this stage, there is a linear dependency between p_{n^*} and the number n, which varies from 1 to 5 (the first column of Table 6).

This is like the first stage to establish a dependency between p_n and the height h.

The next step ⇒ is to establish a dependency between p and the height h.

For this step ⇒, we select the proportion (the extreme dots of the previous Table 6):

Table 7. Dependency of Braille typeface height on pressure (p_n)
(the extreme dots of the previous Table 6)

n	height h, mm	p_n, MPa
1	$x_1 = 0.331$	$y_1 = 0.201$
5	$x_2 = 0.679$	$y_2 = 2.3798$

$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$ – this is a well-known formula to describe the procedure of drawing a straight line through two dots

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) = \frac{y_2 - y_1}{x_2 - x_1} x - \frac{y_2 - y_1}{x_2 - x_1} x_1 = b_2 \times x - b_2 \times x_1$$

$$y = b_2 \times x + y_1 - b_2 \times x_1 = b_2 \times x + a_2; \quad a_2 = y_1 - b_2 \times x_1.$$

Here, y corresponds to the pressure p_n, and h ⇒ to the dots x. As a result:
$p = p_h = a_2 + b_2 \times h = -1.8714 + \mathbf{6.2609} \times h$ ⇒ for Table 2 (a linear version).
The first basic numeric result: b_2 = **6.2609**. ⇒ for Table 2 (a linear version).

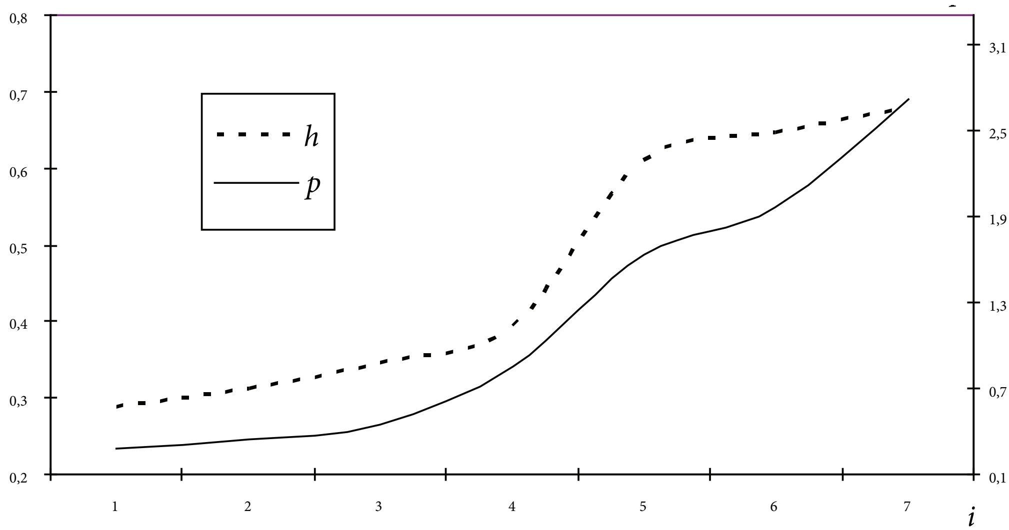

Fig. 1. Dependencies of the height $h = h(i)$, the pressure $p = p(i)$, where i – is a number of the species (for Chromolux cardboard data, the surface mass $m_s = 0.25$ kg/m^2 – Table 2; $i = 1, 2, \ldots, 5$).

Fig. 1 presents the dependencies of the height $h = h(i)$, the pressure $p = p(i)$, where i – is a number of the species (for Chromolux cardboard data according to Table 2; $i = 1, 2, \ldots, 5$). As we can see from the figure, the dependencies are nonlinear.

Using a computer application, we estimate the correlation coefficients between the height and the pressure data for Chromolux cardboard (according to Table 3)

As a result, the numerical value of the correlation coefficient $K_{kor} = 1$ (between the pressure and the height data for the Chromolux cardboard, according to Table 3) has been obtained. Similar values of the correlation coefficients, close to the values $K_{kor} \approx 1$ for the pressure and the height data, have also been obtained for cardboard of other brands.

Using a computer application using the method of least squares and the data for p, we find the nonlinear dependency of the type $p(h) = a \times h^2 + b \times h + c$ between the pressure p and the height h for Chromolux cardboard.

As a result, we get the dependency: $p(h) = a \times h^2 + b \times h + c$.

For Table 2 (Chromolux cardboard) we get:

$$p(h) = 15.26 \times h^2 - 9.151 \times h + 1.789.$$

Table 8.

N	height h, mm	p_k, MPa	p_{lin}, MPa	Δp_{lin}	p_{nel}, MPa	Δp_{nel}
1	0.331	0.394	0.201	0.649	0.432	0.092
2	0.418	0.643	0.746	0.148	0.630	0.020
3	0.505	1.249	1.29	0.032	1.059	0.164
4	0.592	1.454	1.835	0.232	1.720	0.167
5	0.679	2.712	2.379	0.131	2.611	0.038

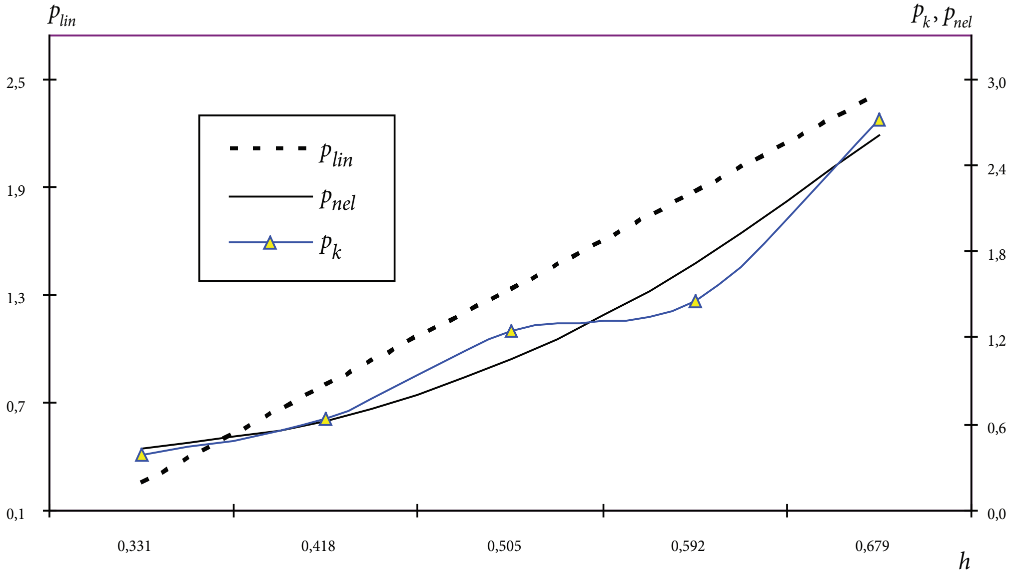

Fig. 2. The values of pressure approximated by the actual $p_k = p(h)$, linear $p_{lin} = p(h)$ and nonlinear $p_{nel} = p(h)$ dependencies on the height h

In this case, the number of the figure corresponds to the number of the table, Chromolux cardboard, the surface mass $m_S = 0.25$ kg/m^2 – Table 2 (Fig. 2).

We define the averaged errors (deviations) by correlations that are similar to the average square deviation:

$$\sigma_{lin} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\Delta p_{lin,i}^2}, \quad \sigma_{nel} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\Delta p_{nel,i}^2},$$

$$\Delta p_{lin,i} = \frac{2\cdot\left(p_{lin,i} - p_{k,i}\right)}{\left(p_{lin,i} + p_{k,i}\right)}, \quad \Delta p_{nel,i} = \frac{2\cdot\left(p_{nel,i} - p_{k,i}\right)}{\left(p_{nel,i} + p_{k,i}\right)}.$$

For Table 2, based on the data from Table 8, we get ($n=5$) $\sigma_{lin} = 0.359$, $\sigma_{nel} = 0.128$ (their correlation $\sigma_{lin}/\sigma_{nel} = 2.8$).

We also get a range of approximate dependencies of the linear type $p_{lin} = p(h)$ and nonlinear type $p_{nel} = p(h)$ between the pressure p and the height h for Chromolux data:

$p_{24} = 15.26h^2 - 9.151h + 1.789$, ($m_s = 0.25$ kg/m^2);
P_2(0,5mm) = 1.029 MPa; P_2(0.55mm) = 1.372 MPa; P_4(0.6mm) = 1.792 MPa;
P_2(0,65mm) = 2.288 MPa; P_2(0,7mm)= 2.861 MPa; $\Delta_{nel} = 0.038$.
$p_2 = -1.8714 + 6.2609h$, ($m_s = 0.250$ kg/m^2);
P_2(0.5mm) = 1.259 MPa; P_2(0.6mm) = 1.885 MPa; P_2(0.65mm) = 2.198 MPa;
P_{24}(0.7mm) = 2.511 MPa; $\Delta_{lin} = 0.131$

The method for calculating the approximate dependencies of the linear type $p_{lin} = p(h)$ and the nonlinear type $p_{nel} = p(h)$ between the pressure p and the height h for Chromolux cardboard can be used for other types of cardboard.

Conclusions

The main parameters on which the technological efforts in cardboard (i.e. pressure p) depend on are the height h and the mass of the cardboard m_s.

The technological efforts in the cardboards (pressure p) do not need to be determined depending on the thickness z and the volumeric density ρ, since the dependencies $p = p(z)$, $p = p(\rho)$, $p = p(m_s)$ are equivalent, this means the correlation coefficient between them is close to one ($K_{kor} = 0.95 \div 1$).

To compare the technological efforts in the cadboards, that is, the pressure p, p must be compared for the same values of the height h and for the surface mass m_s.

To compare the analytical dependencies of the type $p = p(m_s)$, $p = p(h)$ for the cardboard, a graphical method has been used, since the dependencies on the graphs are visual and allow to do some analysis and establish local conclusions about the course of dependencies, that is, the conclusions about larger or smaller values of the pressure and the inclination of the curves or direct corresponding segments.

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Streszczenie

Badanie formowania wysokości znaku Braille'a na tekturze Chromolux

Artykuł prezentuje badania zależności wysokości elementów alfabetu Braille'a na tekturze Chromolux od parametrów technologicznych oraz wartości nacisku. W celu wyjaśnienia analitycznych współzależności pomiędzy naciskiem (p) i parametrami procesu (h, m_S), dokonano przekształcenia nierównych przedziałów h i m_S na równe, tj. Spełniające zależności Δh = const, Δm_S = const. W opisywanym przypadku do wyznaczenia nieliniowych i liniowych zależności w postaci $p = p(m_S)$, $p = p(h)$ użyto interpolacji oraz metody najmniejszych kwadratów.