KAUNAS UNIVERSITY OF TECHNOLOGY

INGRIDA VENYTĖ

INVESTIGATION OF THE PHYSICAL-MECHANICAL PARAMETERS OF BRAILLE DOTS AND RELIEF ELEMENTS

Summary of Doctoral Dissertation
Technological Sciences, Materials Engineering (08T)

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KAUNO TECHNOLOGIJOS UNIVERSITETAS

INGRIDA VENYTĖ

BRAILIO RAŠTO TAŠKŲ IR RELJEFINIŲ ELEMENTŲ FIZIKINIŲ-MECHANINIŲ PARAMETRŲ TYRIMAS

Daktaro disertacijos santrauka
Technologijos mokslai, medžiagų inžinerija (08T)

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INTRODUCTION

About 285 millions people have visual handicaps, of which 39 millions are blind and 90 percent live in developing countries. According to the data of the Lithuanian Association of the Blind and Visually Handicapped, over 7 thousands of visually handicapped people live in Lithuania but it is believed that this number is much higher. In the European Union there are 7.4 million people with such disabilities, and even more in the entire Europe.

An increasingly important social issue is the integration of people with disabilities. Not only state and legal representatives are looking for the solution of this global problem; industry workers and creators of technologies are also involved in this. The European Blind Union and national organizations of blind people of Western countries are trying to make all kinds of information as widely accessible as possible.

In recent years, the tools of information transfer for the blinds are developing increasingly. Electronic reading tools are designed for converting the text information into the audio. But today Braille is still one the most important information transfer tools. The laws of Braille systems are scientifically based, and over more than 180 years no one could change or correct it. Statistically about 90 percent of working blind people are able to read Braille (from 7 thousand members of Lithuanian association of blind and visual handicapped about 2 thousands can read), and for these people this is the most important tool to understand the information independently.

Running the EU directive 2004/27/EC since late October, 2005, information in Braille should be provided on all pharmaceutical packages. This requirement fully inured on 01.01.2012, and is currently used and can be found only on paperboard pharmaceutical packages.

However, in the future it would be appropriate to use Braille not only on pharmaceutical packages but also and on other purpose goods – food, clothing, chemistry products packages and labels made from different materials (polymer, textile, foil, metal, glass and etc.) because the lack of information restricts the right of choice when the blind people buy the products. This also allows to integrate the blind people more into the society and increase the mobility and independence.

The Lithuanian Association of the Blind and Visually Handicapped, sciencists of Ukrainian Academy of Printing and Warsaw University of Technology are the cooperation partners analyzing the Braille need on packages and labels. Lithuanian printing houses do not have the procedure of Braille printing based on scientific research that would be suitable for different printing types and materials.geometrical parameters so that a blind person could read it regardless of his age.

In this dissertation, new Braille dots printing technologies on various materials are investigated and proposed by applying special Braille forming materials. The stability of geometrical and physical parameters of Braille dots was investigated and numerical modelling of physical parameters was carried out.

Research aim and objectives

The aim of the dissertation is to determine the stability of physical-mechanical parameters of Braille dots and relief elements, considering the materials, the forming type and the performance conditions.

The aim of the research can be reached carrying out the following **objectives**:

1. Carry out the review of scientific literature references of Braille dots and relief elements.
2. For various age groups, determine the parameters of Braille formed by using different printing technologies that meet the requirements of blind people.
3. Create the procedure intended to carry out the experimental and numerical researches of geometrical and physical parameters Braille dots and relief elements.
4. Carry out the research of geometrical and physical parameters of Braille formed in different ways on various materials (paper, paperboard, textile, polymer, foil), assessing the properties of materials, climatic and performance conditions.
5. Carry out the optimization of printing technological regimes of Braille formed on adhesive labels using digital printing and on paper using screen printing.
6. Carry out the experimental research of Braille dots and relief elements using photoelasticity method and numerical modelling of physical parameters.

Research novelty and importance

By using different procedures, the stability of geometrical, mechanical and physical parameters of Braille formed using different technologies and materials was researched. The geometrical and physical parameters of Braille dots were studied using special inks and varnish. The materials suitable for Braille printing and optimal printing technological parameters were determined. The distribution of stresses in the products with Braille and relief elements was determined that has direct effect on the final quality of products.

Modern experimental and numerical research methods were applied for carrying out the research, and the methodology was created upon the base of scientific articles, data and recommendations provided by the manufacturers.

Based on the research data, the application of Braille has been expanded, which has opened wider prospects for blind people's integration into the society.

The procedure and recommendations were created for Braille formed on different materials.

Statements to be defended

1. The main geometrical parameters of Braille embossed on pharmaceutical packages (height, diameter and distance between Braille dots) determine correct information reading by blind people in different age groups.
2. Mechanical effect, temperature and ageing negatively affect the geometrical, mechanical and physical parameters of Braille formed on different materials.
3. Printing velocity, pressure and temperature of varnish affect the dimensions of Braille dots formed using digital printing.
4. The use of new materials in screen printing (screen printing inks with thermo powder) allow us to form Braille dots with better relief.
5. The residual stresses formed in polymeric products with Braille and relief elements reduce the durability of these products.

Research approval

The research was carried out in the international research project: International Lithuanian (KTU) – Lehigh University (LU, USA) research project *"Development of novel optical methods for defectoscopy of polymer films for polygraphic and packaging manufacturing"* (project duration: 2012–2015). The managers of the research projects: KTU Prof. Dr. Habil. Edmundas Kibirkštis and LU Prof. Dr. Habil. Arkady Voloshin.

The subject of the dissertation has been discussed in 11 publications; 4 of them published in ISI Web of Science publications with a citation index. In addition, one paper has been prepared and submitted to the journal „Materials Science“, another paper is being prepared after a review for the journal „Microscopy Research and Technique“. The list of publications is presented at the end of the summary.

The findings of the study have been presented at 5 International, 3 National and other conferences.

Scope and structure of the dissertation

The dissertation consists of the introduction, 4 parts, the main generalized conclusions, a list of references containing 98 sources, and a list of the author's publications related to the dissertation. The dissertation contains 107 pages, 86 illustrations, 18 tables and 7 pages of annexes.

1. OVERVIEW OF THE RESEARCH METHODS

Mostly the Braille and relief elements are printed using embossing. However, recently other Braille forming types are also applied i.e., screen printing, thermography, digital ink-jet printing and others. Deeper research of these printing types could expand the applications of Braille on various materials, thus creating better possibilities to integrate the blind people in the society.

Since Braille is read by touching, the factors of the touching mechanism of the person's finger pads are important. One of the peculiarities causing the quality of Braille reading is the age of Braille readers.

The physical and consumption properties of materials are important for products with Braille. The qualitative reading of Braille and relief elements depends on the surface of the materials on which they are formed. Since the surfaces of materials differ in their topography and are recognized differently, a lot of research has been carried out concerning this problem. It has been determined that coefficients of friction between the human finger and the surface of the material describe these differences. When analyzing the literature sources, it was noticed that many studies are focused on the effect of roughness of a material on friction between the finger pad and the material surface. It was determined that the coefficient of friction of coated paper and other materials with flat surface is higher than uncoated materials, thus by touching these materials the relief surface is understood better. The research of Braille dots height formed by using embossing and screen printing was carried out in Birmingham University during which the minimal height, readability and permissible sizes of Braille parameters were determined. The analysis of literature has shown that the most important parameters of Braille are height, distances between dots and diameter, thus each separate parameter and their entirety are important in the readability of Braille.

The analysis of literature has shown that there are not sufficient studies that would analyze the stability of Braille parameters when Braille is formed on different materials and using different forming types. Braille is read by touching, therefore the research of stability of Braille in different materials, experimental and numerical research of the influence of Braille climatic and performance factors are of prime importance.

2. EXPERIMENTAL OBJECT AND THE METHODS

Research object – printouts with Braille formed on different materials using different technologies.

In this chapter the most suitable materials and methods used for Braille forming are presented. The following research was carried out:

- The determination of dispersion of geometrical parameters of Braille embossed on pharmaceutical packages and factors affecting the quality;

- The research of mechanical effect on Braille formed on different materials;
- The research of ageing effect and temperature factors on Braille formed on different materials;
- Optimization of technological parameters of Braille formed on adhesive labels using digital printing;
- Determination of materials suitable for Braille printing using screen printing;
- Determination of residual stresses in polymeric films with Braille using photoelasticity method.

The materials and methods of Braille forming used for the research are listed in Table 1.

Table 1. Materials and Braille forming methods used for experimental researches

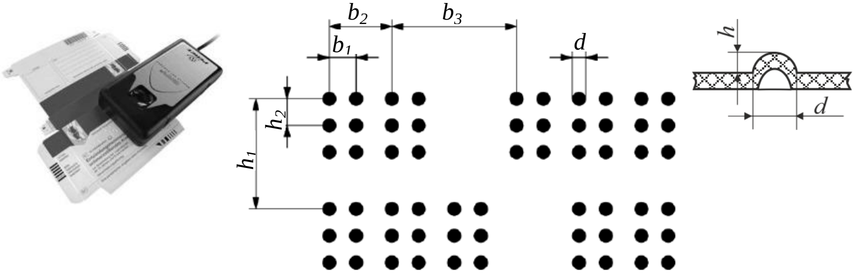
Material type, name	Braille forming methods	Applications
Paperboard Arktika GC1, cellulose pulp, 250 g/m^2	Embossing Screen printing Thermography Digital printing	Pharmaceutical, food products packages
Paperboard Alaska GC2, cellulose pulp, 250 g/m^2	Embossing Screen printing Thermography Digital printing	Pharmaceutical, food products packages
Paperboard Alaska GC2, cellulose pulp, 275 g/m^2	Embossing	Pharmaceutical, food products packages
Paperboard Multicolor Mirabell GD2, recycled pulp, 250 g/m^2	Embossing Screen printing Thermography Digital printing	Pharmaceutical, food products packages
Paperboard Multicolor Mirabell GD2, recycled pulp, 320 g/m^2	Embossing	Pharmaceutical, food products packages
Paper Polaris, coated, 115 g/m^2	Screen printing Thermography Digital printing	Candies, chocolate packages
Paper Munken Pure, uncoated, 90 g/m^2	Screen printing Thermography Digital printing	Candies, chocolate packages, books, calendars
Textile 100 % cotton	Screen printing	Clothing labels
Textile 100 % polyester	Screen printing	Clothing labels
Polymer PP, adhesive	Screen printing	Adhesive labels
Al foil	Screen printing	Closures of food containers
Paperboard Plike, cellulose pulp, 250 g/m^2	Screen printing	Pharmaceutical, food products packages

Different materials and Braille forming methods were chosen in order to expand the applications of Braille and apply the findings of the research in practice. The samples were acclimatized before testing. All tests were carried out under these climatic conditions: +21±1°C temperature and 50±2 % relative humidity (EN ISO 186). At the beginning of testing the samples were read by the blind people (n = 36) divided in groups by age: up to 25 years of age (n = 10), 26–45 years old age (n = 8), 46–60 (n = 10), over 60 years age (n = 8), from which 88 % persons have an innate disability and 12 % persons began to read Braille only a few years ago. The reading time of Braille was chosen 10 s, assuming the average Braille reading speed 100 words per minute considering to the literature analysis of researches about Braille reading speed.

Procedure and testing equipment of dispersion of geometrical parameters and factors affecting the quality of Braille

11 samples were used for testing dispersion of Braille geometrical parameters i.e., the pharmaceutical packages of different manufacturers (Liuks, Valentis, Sanitas) having Braille formed by using embossing and made from two different types and grammage paperboards: Multicolor Mirabell GD2 (from recycled pulp) 320 g/m^2 and Alaska GC2 (cellulose mass) 275 g/m^2. These paperboards can be used for manufacturing pharmaceutical packages with Braille and have different properties.

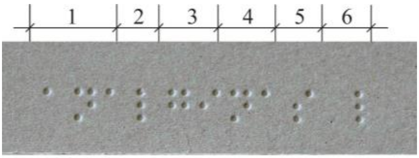
The samples were chosen from different Lithuanian printing houses in order to determine the quality of Braille forming.



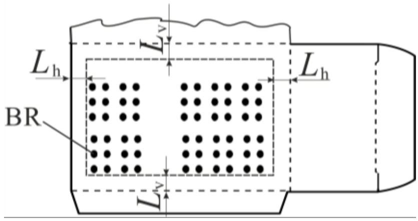
a b

Fig. 1. Measuring device FAG BRAI³ Braille Dot Checker of Braille geometrical parameters (a) and main parameters of Braille (b): d – Braille dot diameter; b_1 – horizontal distance between Braille dots; b_2 – horizontal distance between Braille elements; b_3 – distance between Braille words; h_1 – distance between Braille lines; h_2 – vertical distance between two Braille dots centres; h – Braille dot height

The measurements of Braille height h and others Braille parameters (see Fig. 1 b) and the positioning of Braille from package (see Fig. 2 b) bending line were carried out using special Braille reading device FAG BRAI³ Braille Dot Checker (see Fig. 1 a).



a



b

Fig. 2. The example of measuring of six Braille lines (a) the positioning of Braille from package bending line (b): L_h – distance of Braille from package horizontal side; L_v – distance of Braille from package vertical side

The measurements were carried out along each Braille line up to 6–11 zones (see Fig. 2 a) measuring the upper and lower part of each element. The different number of zones was chosen due to the different number of Braille elements, words and lines. The quality of Braille reading was assessed by the blind people (n = 36).

Procedure and testing equipment of mechanical effect to Braille printouts

During exploitation the packages and labels are affected by various factors, mechanical included. In order to assess the effect of mechanical abrasion on Braille geometrical parameters, experimental tests were carried out using samples with Braille formed by using different types (embossing, screen printing, digital printing, thermography) and on different materials (paperboard Arktika GC1 250 g/m^2, paperboard Multicolor Mirabell GD2 250 g/m^2, paper Polaris 115 g/m^2, paper Munken Pure 90 g/m^2, textile 100 % cotton, textile 100 % polyester, polymer PP, Al foil) (see Table 1) having different mechanical and physical properties. Braille was formed using different forming types because these technologies allow to form relief element including and Braille. These materials were chosen because of their wider applications for packages and labels.

During the tests it was investigated how the mechanical abrasion changes the geometrical parameters of Braille dots. Experimental stand of Oser type was used for determining the change of Braille geometrical parameters under cyclic mechanical abrasion (Fig. 3 a, b).

During the experiment the samples were subjected to mechanical force and at set intervals (from 1 min to 60 min that corresponds 1692 abrasion path length) the measurements of Braille dot height *h* and Braille diameter *d* were taken using the above described FAG BRAI³ Braille Dot Checker.

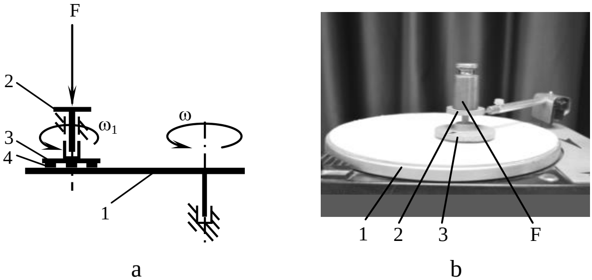


Fig. 3. Experimental equipment scheme of Braille resistance to mechanical effect: a) equipment kinematic scheme: *1* – disc, *2* – holder, *3* – sample claim diskette, *4* – samples, *F* – contact force, ω, ω_1 – angular speed of disc and samples diskette; b) equipment view

Digital images were captured by a microscope with digital camera DN-CAM and FAG BRAI³ Braille Dot Checker in order to analyse the quality of the surfaces of Braille dots. The quality of Braille reading was assessed by the blind people (n = 36).

Procedure and testing equipment of effect of temperature factors and ageing of on Braille formed on different materials

The packages or labels used for food or drugs and marked with Braille must be stored in the refrigerator or in a dark and cool place. Experimental tests were carried out in order to assess the effect of temperature on Braille geometrical parameters using the samples: Braille formed using embossing on different paperboard type (paperboard Arktika GC1 250 g/m^2, paperboard Multicolor Mirabell GD2 250 g/m^2) and Braille formed using screen printing on different materials (paperboard Arktika GC1 250 g/m^2, paperboard Multicolor Mirabell GD2 250 g/m^2, paper Polaris 115 g/m^2, paper Munken Pure 90 g/m^2, polymer PP, Al foil) (see Table 1). The effect of ageing on Braille geometrical parameters was determined by using different types paperboard (Arktika GC1 250 g/m^2, Multicolor Mirabell GD2 250 g/m^2) for Braille formed using embossing.

Based on the terms and conditions of various drugs and food –15 ^{o}C and +5 ^{o}C temperature was chosen for the testing. The measurements of Braille dots height *h* were carried out using FAG BRAI³ Braille Dot Checker Braille. The dot height was measured by storing the samples 14 and 29 days (averaged interval of drugs and food storing in refrigerator was chosen). The effect of ageing on Braille was determined after 6 and 12 months at +21±1 °C temperature and 50±2 % relative humidity.

Procedure and testing equipment of optimization of technological parameters of Braille formed in adhesive labels using digital printing

The object of these tests were the printouts with Braille formed using digital ink-jet printing machine with special clear varnish Braille maker Varnish 1.0 A. Braille dots were printinted on two different adhesive label materials: a) on paper PrimeCoat MC S2000, b) on polyethylene film FASSON PE85 WHITE S692N-BG40WH. The values of printing velocity and the temperature of varnish were determined at which the optimal Braille geometrical parameters are formed. The geometrical parameters of Braille were assessed changing technological conditions (varnish temperature 51–59 °C, varnish supply pressure $(2–3)\times10^5$ Pa, printing velocity 0.25–0.75 m/s).

Procedure and testing equipment of determination of materials suitability for Braille printing using screen printing

During Braille printing it is important to form the dots of appropriate size because the height of Braille dots decreases when they are curring.

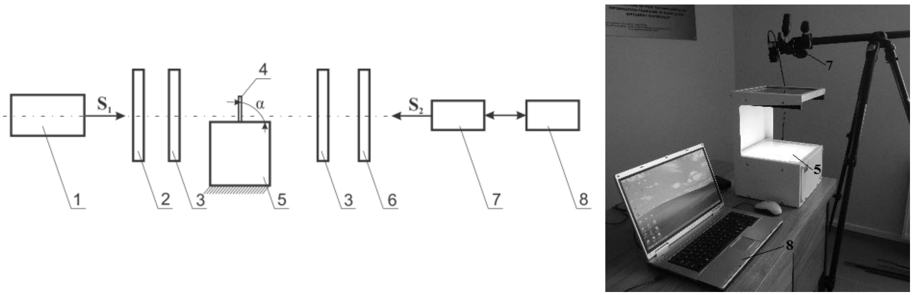
Experimental tests were carried out in order to choose the suitable materials for Braille printing during which the thermal effect on the change of Braille ink mass was determined. The relief images were printed on paperboard Plike (coated, cellulose mass, heat resistance, 250 g/m^2), using screen printing machine TX-2530, screen printing inks and their composition with thermal powder. The following types of samples were used during experimental tests: sample printed with screen printing inks (sample 1); sample 2 c screen printing inks+thermo powder; sample 3 – screen printing inks+paperboard; sample 4 – screen printing inks+thermo powder+paperboard. In order to achieve the relief elements of special height Braille printouts were cured up to 200 °C temperature at curring time 15÷35 s. Water based screen printing inks PASSAD AQ 0-51 and the composition of these inks with thermo powder that consists of 55÷75 % screen printing inks PASSAD AQ 0-51 and the rest part are the additives that consist of thermoplastic material styrene and maleic anhydride (12÷22 %) and solvent dimethyl sulfoxide (13÷23 %) were used for the tests.

Thermal stability was assessed by carrying out the quality analysis of Braille printouts. It was determined by analysing the thermograms obtained using derivatograph Q-1500 D. The samples were analysed under dynamic regime at heating velocity 5 °C /min in the room. The mass of samples was 200 mg. The standard material was aluminium oxide. Determining the decay boundaries of Braille inks, the samples were heated up to 350 °C temperature. Applying the method of thermogravimetric analysis (TGA) the change of material mass (TG curve) was registered by heating the sample up to high temperature. In this case the thermal stability, processes of destruction were determined. The first derivative (DTG curve) was recorded together with TG curve. The biggest velocity of sample mass decrease was determined by analysing the obtained curve of differential thermogravimetry (DTG).

The images of Braille elements were analysed using microscope. A specially designed testing scale made from clear film and the above described equipment were used for quality control of Braille geometrical parameters.

Procedure and testing equipment of determination of stresses of Braille formed on polymeric materials

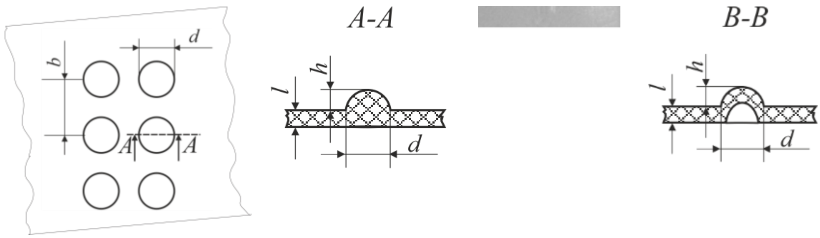
During the forming process of Braille dots or images in a polymeric film usually optical isotropic material residual stresses can be found that can negatively affect the qualitative parameters of Braille. The method of photoelasticity was used for the determination of stresses distribution in a polymeric material with Braille elements or images. A special experimental stand was designed for testing (see Fig. 4).



a b

Fig. 4. Structural scheme and view of the stand for photoelastic stresses distribution determination: a) structural scheme of General Purpose Strain Viewer: *1* – light source; *2* – polarizer; *3* – plate of a quarter of a wave length; *4* – sample (polymeric film with Braille writing); *5* – background on which a sample is located; *6* – analyzer; *7* – digital camera EO-1312c; *8* – personal computer; S_1 – direction of propagation of a light beam; S_2 – direction of observation; α – angle of inclination of a polymeric film; b) view of the stand and General Purpose Strain Viewer

6 samples were tested: the first two were made from clear polymeric film (PVC) with clear Braille dots printed using screen printing, the third sample was made from clear polymeric film (PVC) with clear Braille dots formed using thermoforming type, the fourth and fifth samples were made from polymeric material PET (polyethylene terephthalate) and the sixth sample – PP (polypropylene) package with Braille formed using thermoforming. These materials are used for food and non food packaging.



a b c d

Fig. 5. Schematic view of samples: a) top view of Braille: *d* – diameter of Braille dot, *b* – distance between dots of Braille; b) side view of Braille formed on polymeric material using screen printing (*A-A*): *l* – thickness of polymeric material, *h* – Braille dot height; c) embossed relief view; d) profile view of relief element (*B-B*): *l* – thickness of polymeric material, *h* – height of relief graphic element, *s* – width of relief graphical element

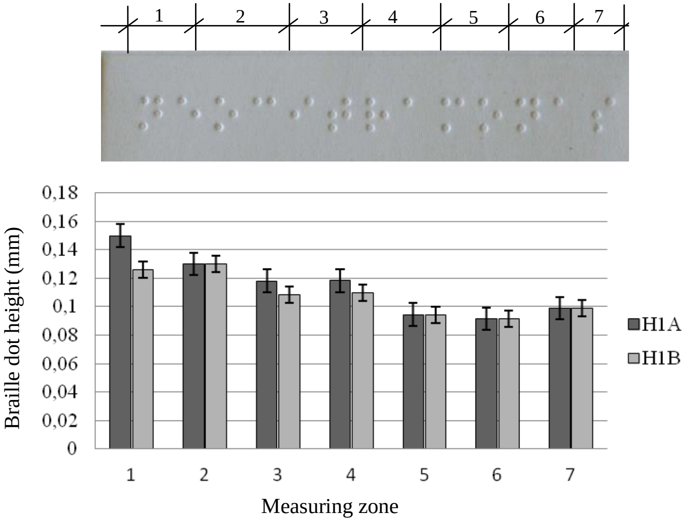
The level of stresses was assessed at the static state of the sample and at different angles. The color pattern of stresses was analysed according to the procedure provided by the company “Sharpless”. The schematic images of samples are shown in Fig. 5. During testing the equipment fixes only the distribution of stresses.

3. FINDINGS OF EXPERIMENTAL RESEARCHES

Findings of research of dispersion of geometrical parameters and factors affecting the quality of Braille embossed on pharmaceutical packages

The value of embossed Braille dot height changes depending on the position of the dot in an element and a line. The height of Braille dots differs in upper *(A)* and lower *(B)* parts of elements, at the beginning and end of Braille line and in different lines (*H1*, *H2*, *H3*) (see Fig. 6). The differences were observed in samples provided by different manufacturers. This can be explained by the fact that during embossing the pressing force of the matrix distributes unevenly. Such a high dispersion field of measurements data (0.04–0.06 mm) means that a Braille word or text could be unreadable due to an improperly formed at least one element.

It was determined that the value of Braille dot diameter directly affects other geometrical parameters b_1, b_2, b_3, h_1, h_2 (see Fig. 1, b). The positioning of Braille from the package horizontal side is partially satisfied but from the vertical side about 37 % exceeds the estimated values. Braille formed on paperboard Multicolor Mirabell GD2 was read best because this material is soft and fluffy thus allows embossing Braille dots of 0.17–0.19 mm height (see Fig. 6, b).



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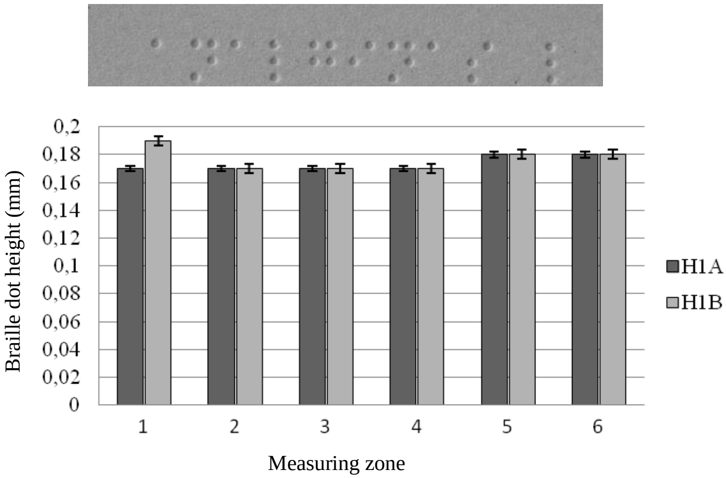


b

Fig. 6. Findings of dispersion of Braille dot height *h* embossed on paperboard Alaska GC2 275 g/m^2 (a), on paperboard Multicolor Mirabell GD2 320 g/m^2 (b): H1A – height of Braille dots of first line in the upper part of element; H1B – height of Braille dots of first line in the lower part of element

Braille formed on packages provided by manufacturer Valentis was hard to read by the blind people because the distances between dots were formed improperly. The reading quality of older age people (over 60 years old) is affected by the height of Braille dot (which value is 0.09 mm) and the distance between Braille dots (not higher than 2.51 and not smaller than 2.00 mm).

Findings and their analysis of research on the effect of mechanical abrasion on Braille formed on different materials

The findings of experimental test of resistance to mechanical abrasion of Braille dots formed using screen printing and embossing on different materials are shown in Fig. 7.

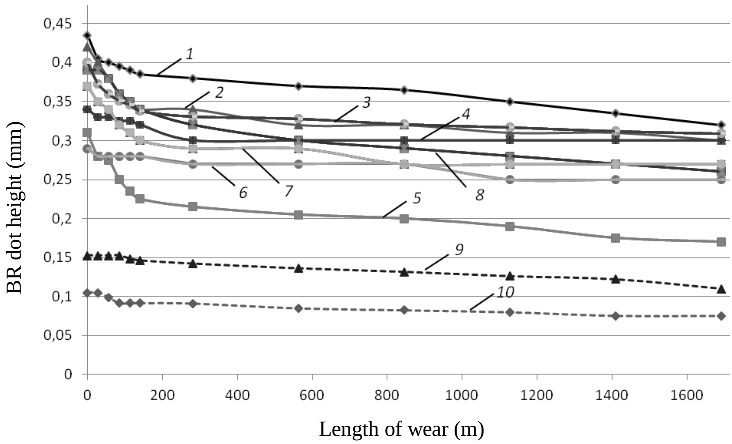


Fig. 7. Braille dot height change under different mechanical effect way length (abrasion time – 60 min) when Braille is formed using screen printing on different materials: *1* – on textile cotton, *2* – on textile polyester, *3* – on paper uncoated Munken Pure, *4* – on paper coated Polaris, *5* – on paperboard Arktika GC1, *6* – on paperboard Multicolor Mirabell GD2, *7* – on Al foil, *8* – on polymer PP, when Braille is embossing on different materials: *9* – on paperboard Multicolor Mirabell GD2, *10* – on paperboard Alaska GC1

As can be seen (see Fig. 7) from the given curves the change of Braille dots height h formed using embossing after mechanical abrasion (effect time – 60 min and effect path length – 1692 m) is higher for Braille formed on recycled mass paperboard (Multicolor Mirabell GD2) packages. The Braille height decreases 31 % from the initial Braille dot height meanwhile the change of the height of Braille dots formed on cellulose mass paperboard (Alaska GC2) packages is 26 %. The change of Braille dot height formed using screen printing on different materials is different: Braille dot height formed on paperboard Arktika GC1 decreased – 45 % (see Fig. 8), on paperboard Multicolor Mirabell GD2 – 14 %, on cotton textile 27 %, on polyester textile 29 %, on coated paper

Polaris – 23 %, on uncoated paper Munken Pure – 12 %, on polymer PP – 33 %, on Al foil – 26 % from the initial value of dot height. Depending on the materials type on which the Braille is formed using screen printing the relief dots wears differently (in interval 12–45 %). This is caused by plastisolic inks that adhere to the material surface differently during printing due to different macromolecular interaction of materials and structural properties (porosity). It should also be noted that when changing the time of the mechanical effect and by decreasing the height of dot, the diameter increases (about 10 %) and the distance between dots also changes, i.e., the bigger diameter, the smaller the distance. These changes are caused by the applied mechanical force that compresses the dots formed using plastisolic inks. Plastisolic inks are polymer thus they deform when the applied force is bigger than intermolecular.

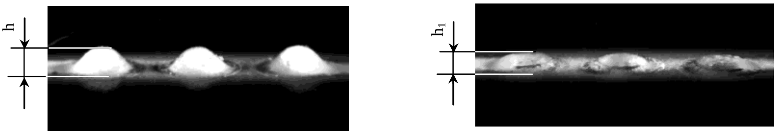
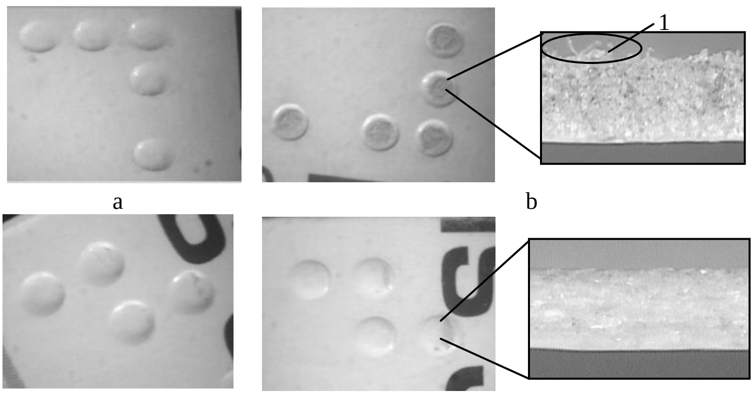


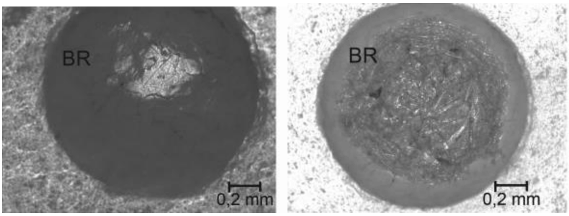
Fig. 8. Digital images of Braille dot when Braille is formed using screen printing on paperboard Arktika GC1 250 g/m^2 when Braille dot height before experimental test h = 0.31 mm, Braille dot height after 60 min of mechanical effect h_1 = 0.17 mm



c d

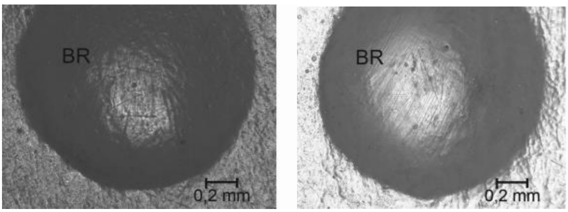
Fig. 9. Digital images of Braille dot surface before and after mechanical wearing when Braille is formed using embossing: paperboard Multicolor Mirabell GD2 (recycled cardboard) in the beginning of the experiment (a) and after 60 min (b) and paperboard Arktika GC1 (cellulose cardboard) in the beginning of the experiment (c) and in the end (d), *1* – tears

The digital images (see Fig. 8–12) were formed in order to determine the changes of Braille dots surfaces. A significant difference of Braille surface wear between different materials can be seen when analysing the digital images. Braille dot surfaces formed on cellulose mass paperboard Arktika GC1 compress under mechanical effect and wear gradually on small changes of dot height. Meanwhile on the surfaces of Braille dots formed on recycled mass paperboard Multicolor Mirabell GD2 snatches can be seen that complicate the reading of Braille (see Fig. 9). This can also be observed and in microscopic photographs of the surface (Fig. 10).



a b

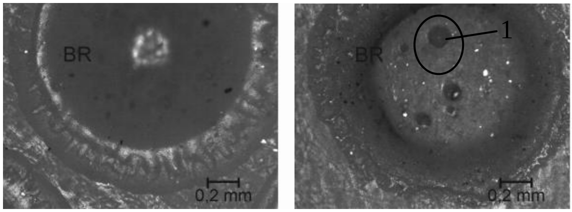
Fig. 10. Digital images of Braille when Braille (*BR*) is formed using embossing on recycled pulp paperboard Multicolor Mirabell GD2 surface before (a) and after mechanical wearing (b), enlarged 75



a b

Fig. 11. Digital images of Braille when Braille (*BR*) is formed using embossing on cellulose pulp paperboard Arktika GC1 surface before (a) and after mechanical wearing (b), enlarged 75

Braille dots formed using screen printing on different materials also change differently. Local segregations of plastisolic inks were observed in Braille dots formed on paperboard Arktika GC1 (see Fig. 12). Thus, when using such a forming type, recycled mass paperboard Multicolor Mirabell GD2 is more suitable.



a b

Fig. 12. Digital images of Braille when Braille (*BR*) is formed using screen printing on cellulose pulp paperboard Arktika GC1 surface before (A)) and after mechanical wearing (b), enlarged 75, *1* – local segregations

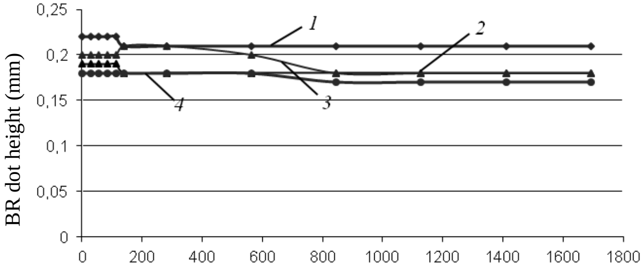


Fig. 13. Braille dot height change under different way of mechanical effect (abrasion time – 60 min) when Braille is formed using thermography printing on different materials: *1* – on cellulose pulp paperboard Arktika GC1, *2* – on recycled pulp paperboard Multicolor Mirabell GD2, *3* – on uncoated paper Munken Pure, *l* – on coated paper Polaris

The height of Braille dots formed using thermography and digital printing changes very slightly after mechanical effect. This can be seen in the diagram shown in Fig. 13.

All samples were read by the blind people at the beginning of tests of mechanical effect. After the mechanical effect, Braille formed using embossing was hard to read when Braille dot height was up to 0.1 mm or due to existing snatches on the surfaces of dots. Braille formed on paperboard Arktika GC1 using screen printing was not read by the blind people. In this case the height of dots was 0.17 mm.

Findings of research on the effect of temperature factors and ageing on Braille printouts formed on different materials

During the tests it was determined that Braille formed using embossing is less resistant to temperature factors and ageing. But the changes of Braille dots are not so significant and change in an interval 0.02–0.04 mm (see Fig. 14) because the time of testing was not so long. For the testing of temperature factors Braille dot height was measured storing the samples 14 and 29 days choosing the average time for storing drugs and food in the refrigerator. For the determination of the effect of ageing, the Braille dots were measured after 6 and 12 months at +21±1°C temperature and 50±2 % relative humidity.

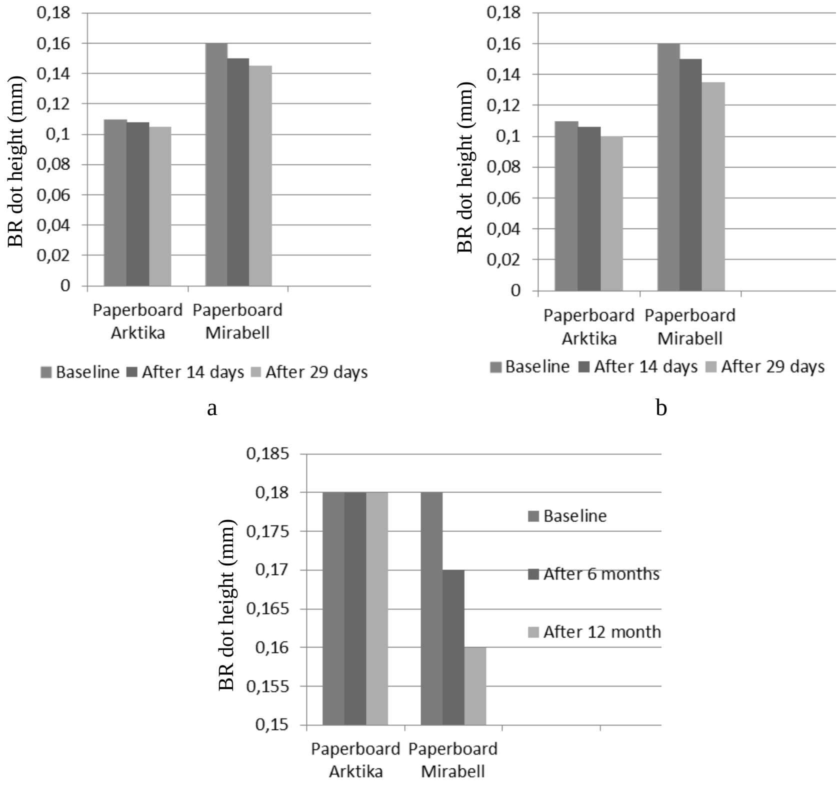
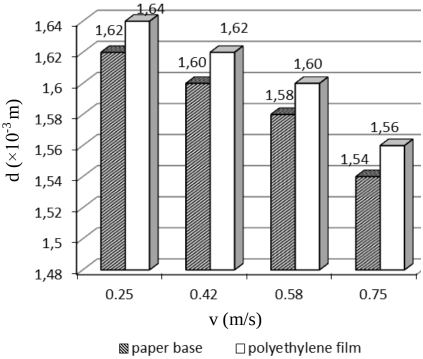


Fig. 14. Findings of Braille dot change formed using embossing on different type paperboard at temperatures +5 ^{o}C (a) and –15 ^{o}C (b) and ageing at +21 °C temperature (c)

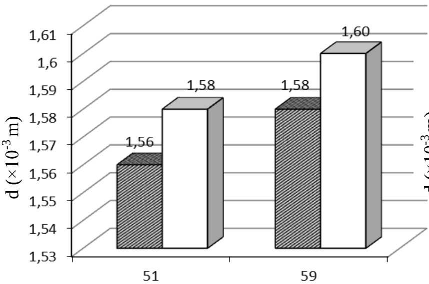
The climatic factors do not have effect on Braille dot height formed using screen printing because plastisolic inks characterize as resistant to the environmental effect.

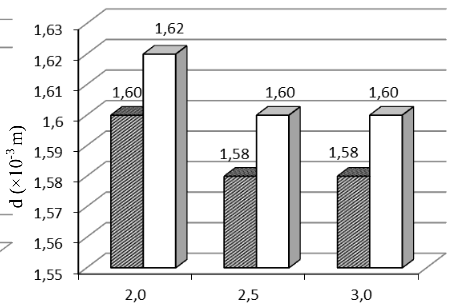
Optimization of technological parameters of digital printing forming Braille on adhesive labels

In order to determine optimal values of Braille printing velocity and temperature and pressure of varnish, the effect of technological parameters on Braille geometrical parameters (height *h* and diameter *d*) was determined. Braille dots were formed on two different materials of adhesive labels. The findings are shown in diagrams in Figs. 15–16.



a





b c

Fig. 15. Dependence of the Braille dots diameter *d* on printing technological regimes: a) on substrate feed rate *v*, when varnish temperature *t* = 59 °C, pressure in the nozzle *P* = 2.5×10^5 Pa, b) on varnish temperature *t*, when substrate feed rate *v* = 0.58 m/s, pressure in the nozzle *P* = 2.5×10^5 Pa, c) on pressure in the nozzle *P*, when varnish temperature *t* = 59 °C, substrate feed rate *v* = 0.58 m/s

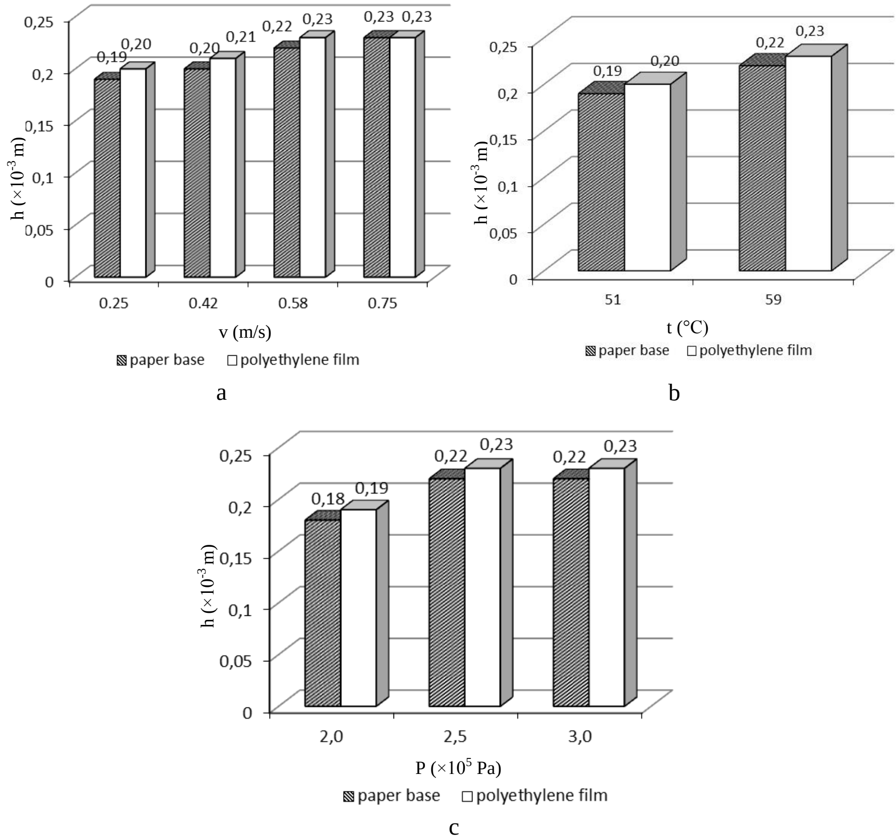


Fig. 16. Dependence of the Braille dots height *h* on printing technological regimes: a) on substrate feed rate *v*, when varnish temperature *t* = 59 °C, pressure in the nozzle *P* = 2.5×10^5 Pa, b) on varnish temperature *t*, when substrate feed rate *v* = 0.58 m/s, pressure in the nozzle *P* = 2.5×10^5 Pa, c) on pressure in the nozzle *P*, when varnish temperature *t* = 59 °C, substrate feed rate *v* = 0.58 m/s

It was determined that increasing the velocity of digital printing from 0.25 to 0.75 m/s, the diameter of Braille dots decreases and the height increases. The changes in geometrical sizes are affected by the pressure of varnish supply. When increasing the temperature of varnish, its viscosity decreases and such change causes the increase of Braille dot diameter.

Optimal technological regimes of printing were determined after carrying out mathematical–statistical analysis (Table 2.) These technological regimes ensure standard geometrical parameters of Braille dots: Braille dot diameter 1.60±0.10 mm, BR dot height (0.16–0.20)±0.10 mm.

Table 2. Values of Braille geometrical parameters at optimal technological regimes of printing

Technological regimes		Paper: Braille dot diameter, *d*, mm	Paper: Braille dot height, *h*, mm	Polyethylene film: Braille dot diameter, *d*, mm	Polyethylene film: Braille dot height, *h*, mm
Printing velocity of materials *v*, m/s	0.58	1.58	0.22	1.60	0.23
Pressure of varnish *P*, MPa	2.5×10^{5}				
Varnish temperature *t*, °C	59				

The forming of optimal height Braille dot using screen printing. Findings of thermal analysis

In order to choose suitable materials for Braille printing, experimental tests were carried out during which the effect of thermal influence on the mass change of Braille inks was determined. Thermal stability was assessed by analysing the thermograms obtained using derivatograph Q-1500 D.

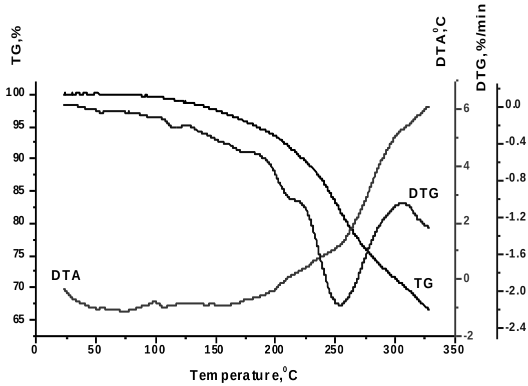
Table 3. Findings of samples thermal analysis

No.	Sample	Stage	Range of temperature, °C	Loss of mass, %
1.	Screen printing inks	1	20–179	4.1
		2	179–214	4.0
		3	214–307	21.5
2.	Screen printing inks + thermo powder	1	20–198	4.1
		2	198–227	2.8
		3	227–295	15.4
3.	Screen printing inks + paperboard	1	20–197	4.8
		2	197–227	4.3
		3	227–306	30.9
4.	Screen printing inks + thermo powder + paperboard	1	20–205	4.8
		2	205–232	4.9
		3	232–309	29.9

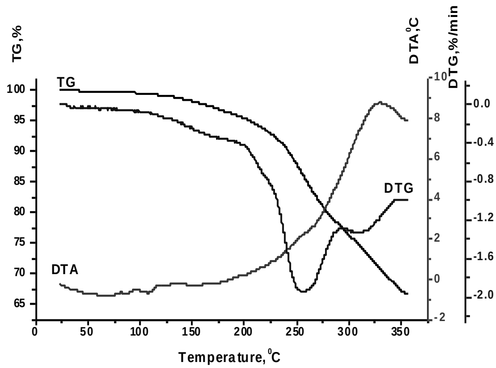
The findings of thermogravimetric (*TG*), differential thermogravimetric (*DTG*) and differential thermal analysis (*DTA*) of Braille inks and printouts on paperboard Pilke are given in Table 3.

The thermograms of the samples were obtained after carrying out the thermal analysis. Fig. 17 shows the thermograms *TG*, *DTA*, *DTG* of screen printing inks (sample 1) and screen printing inks with additives (sample 2).

According to the findings of thermal analysis (Fig. 17), it can be noted that screen printing inks with thermo powder (sample 2) have bigger thermal resistance than screen printing inks (sample 1). The temperature intervals of thermal and thermo-oxidative destruction change to the area of higher temperatures (Table 3). Conversely to Sample 1, Sample 2 loses the mass less intensively when it dilates during heating. This can also be clearly seen at 200 °C temperature.



a

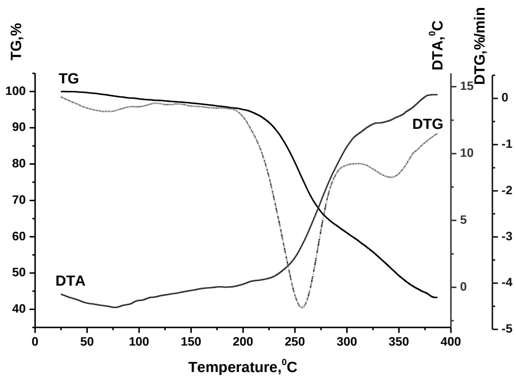


b

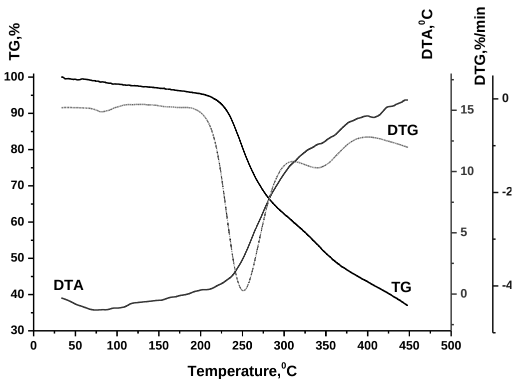
Fig. 17. Experimental thermograms of screen printing inks (sample 1) (a) and screen printing inks with additives (sample 2) (b) (*DTA* – differential curve of thermal changes, *TG* – curve of mass change, *DTG* – differential curve of mass changes)

The thermograms of samples printed on paperboard with screen printing inks (Sample 3 Fig. 18 a) and printed with screen printing inks+thermo powder

(Sample 4 Fig. 18 b) are shown in Fig. 18. A small change of mass can be observed in TG curves for Sample 3 at 20–197 °C (Fig. 18 a) and for Sample 4 at 20–205 °C (Fig. 18 b) temperature intervals. It can be seen that in this interval of temperatures Samples 3 and 4 lose the mass more intensively than Samples 1 and 2. This can be caused by the formation of Braille and the pyrolysis of gaseous products of paper under heating at high temperature. It should also be noted that thermal stability of Samples 3 and 4 is higher than Samples 1 and 2.



a



b

Fig. 18. Experimental thermograms of screen printing inks printed on paperboard (sample 3) (a) and screen printing inks with thermo powder printed on paperboard (sample 4) (b) (*DTA* – differential curve of thermal changes, *TG* – curve of mass change, *DTG* – differential curve of mass changes)

According to the findings of thermal analysis, the determined working temperature range of screen printing inks and inks with thermo powder is listed in Table 3. The thermal analysis has showed that Braille elements printed using screen printing inks with thermo powder should be cured when the working temperature range is 98–198 °C because in this case the obtained relief of Braille dots is better.

The carried out analysis of sample images has shown that Braille dots of appropriate height 0.20×10^{-3} m can be formed using screen printing inks with thermo powder. These inks allow us to compare the Braille dots of higher relief with traditional screen printing inks.

Findings of stresses analysis of Braille formed on polymeric films using photoelasticity method

The residual stresses form when Braille is formed on polymeric materials, which has a negative effect on the durability of data carrier. The distribution of residual stresses was determined by applying the photoelasticity method.

The images of color patterns of stress distribution are shown in Tables 4 and 5.

Table 4. Distribution of stresses of Braille samples (No. 1, 2, 3) formed in polymeric book

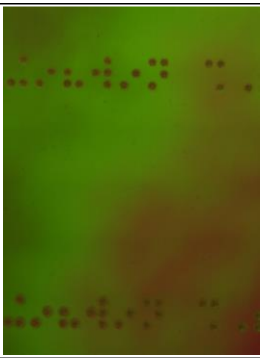
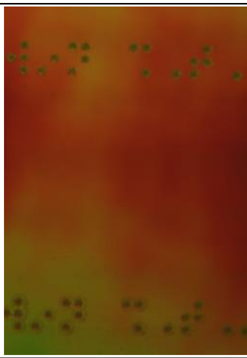
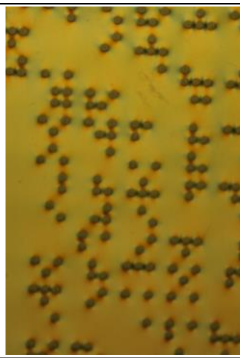
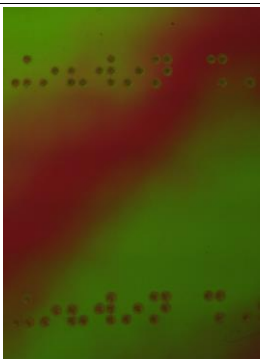
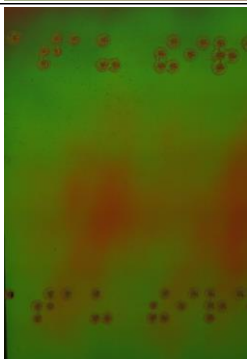
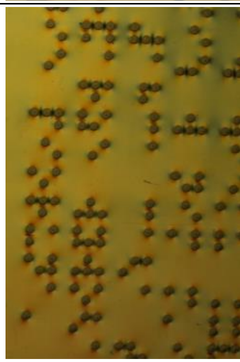
	Sample No. 1	Sample No. 2	Sample No. 3
Initial stage $\alpha = 0°$			
Bending angle $\alpha = 15°$			

Table 4. (continued)

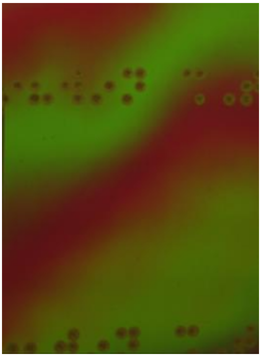
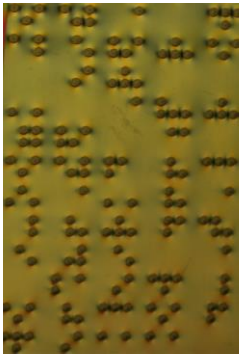
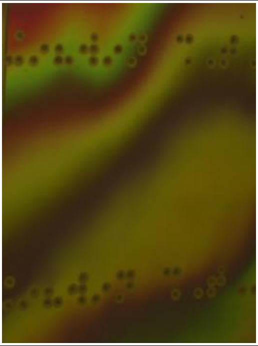
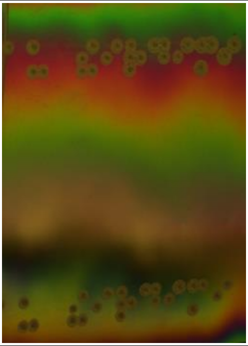
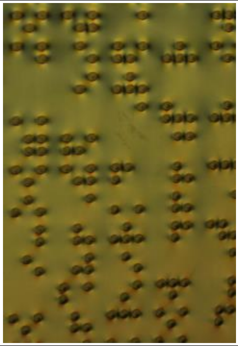
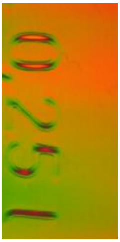
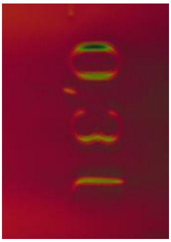
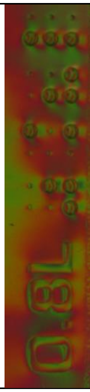
	Sample No. 1	Sample No. 2	Sample No. 3
Bending angle $\alpha = 30°$			
Bending angle $\alpha = 45°$			

Table 5. Distribution of stresses of samples (No. 4, 5, 6) in polymeric material

Sample No. 4	Sample No. 5	Sample No. 6
		

As shown in Table 4, the colour pattern of stresses of Samples 1 and 2 (Braille using screen printing) is similar. At the initial stage and while bending the samples up to angle of 30°, no essential changes can be seen in the colour patterns. When bending the samples up to angle of 45°, in both cases the same first order colours can be seen. Meanwhile at the initial stage of Sample 3 (Braille is formed using thermoforming (embossing)), the level of residual stresses is lower in the areas of Braille than Samples 1 and 2. During the bending, the level of stresses remains the same, thus the bending does not have significant effect. Therefore, it can be concluded that polymeric products with Braille formed using thermoforming (embossing) type (Sample 3) will be more durable. Also it can stated that bending of the samples originates the bending deformations of polymer chains whose size actually is too small to observe the changes of stress level, thus a more detailed analysis using numerical methods is necessary.

From Table 5 it can be seen that colour pattern of stresses in Samples 4, 5, 6 (Braille is formed using thermoforming (embossing)) is similar. The colours of the fourth order (green and pink) dominate, that means the highest values of stresses. In the areas of Braille and relief elements, stresses dominate but the distribution of them is hard to observe, thus the interpretation of the findings should be expanded using numerical methods.

4. NUMERICAL MODELING OF STRESSES IN POLYMERIC MATERIALS WITH BRAILLE AND RELIEF ELEMENTS

The products or publications with Braille are under effect of loadings by reading, thumbing or storing them in the shelves that originate the increase of stresses in polymeric materials and the wear of Braille dots surface. These factors have direct effect on the final quality of the products, therefore it is important to assess the character of stress distribution in Braille and relief elements formed on polymeric clear and isotropic materials. The photoelasticity method is one way to determine the stresses.

In this chapter, with the help of numerical FEM, the procedures were expanded, which allowed us to assess the distribution of stresses of polymeric materials with Braille and relief elements. Numerical and experimental photoelasticity studies complement each other and enable to interpret the fields of stresses in polymeric materials. Calculations were carried out according to the equations, using a program in Borland C++ Builder. The carried out numerical research consists of four parts:

- Applying photoelasticity methods for research of stresses areas in polymeric films;
- Research of stress area in relief elements of two types;
- Research of stress area in Braille dots of two types;
- Research of wear of Braille element in polymeric material.

PET material was used for numerical research. Its mechanical characteristics, like in the mechanical experiment, are as follows: modulus of elasticity E = 14.10×10^8 Pa, Poisson's ratio ν = 0.44, density of the material ρ = 1335 kg/m^3.

Applying of photoelasticity methods for researches of stresses areas in polymeric films

Measurement of stresses in a vibrating polymeric film

During the printing process or during other technological operations of polymeric materials, various dynamic and static loadings take place (vibrations, etc.). Such loadings may cause the increase of stresses in polymeric films. Those factors directly affect the final quality of the printing product, including Braille.

One dimensional model for the investigation of longitudinal vibrations of polymeric film is investigated. Comparison of stroboscopic and time average intensities in images is performed. In the photoelastic research, as the material vibrates according to its own form, the image could be obtained by taking a photograph of the material at the moment when it is extremely bended to its own form. In such a way, the stroboscopic image is obtained whose interpretation is analogical to the interpretation of a static image.

Intensity of the stroboscopic photo-elastic image is expressed as $I = \sin^2 C\sigma_x$, where C is a constant polymeric material.

Intensity of the time averaged photo-elastic image is expressed as

$\bar{I} = \frac{1}{n}\sum_{i=1}^{n}\sin^2\left(C\sigma_x \sin 2\pi \frac{i-1}{n}\right)$, where n is a large integer number.

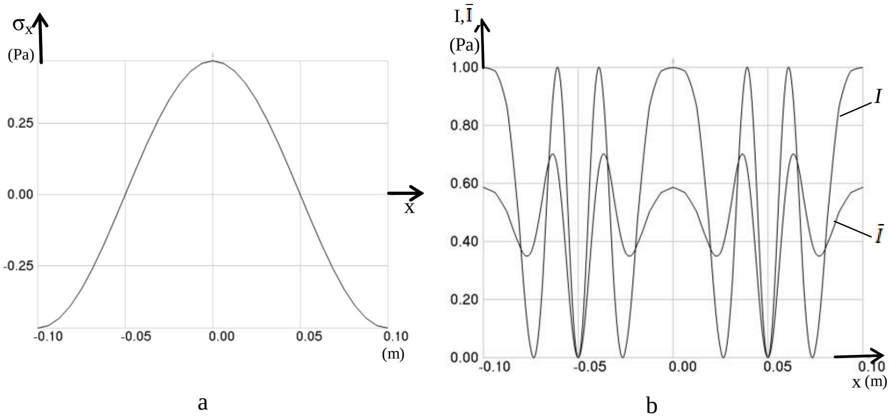


Fig. 19. The second eigenmode stresses (a), intensities of the stroboscopic and time averaged photo-elastic images when n = 64 (b)

The length of the analyzed structure is 0.2 m. On the left and the right ends of the structure the displacements are assumed equal to zero. The second eigenmode stresses (see Fig. 19 a) and intensities of the stroboscopic and time averaged photo-elastic images are presented when $n = 64$ (see Fig. 19 b.)

The presented results also indicate that for precise measurement of stresses it is advantageous to have both stroboscopic and time averaged images. As seen from Fig. 19 b, intensities of stroboscopic and time averaged fringes coincide where the stress is equal to zero.

Investigation of stresses during bending of polymeric material

In the process of bending a sheet of polymeric material, stresses develop in it. The developed numerical procedure is based on the technique of conjugate approximation with smoothing, using two dimensional Lagrange quadratic elements. A composite isoclinic pattern with isoclinics for various directions of the vector of polarization in a plane polariscope is obtained. A circular plate with a fixed internal radius is investigated. This construction is well illustrated by the conjugate approximation procedure. Composite isoclinic patterns for the second eigenmode obtained by using the procedure of conjugate approximation are presented in Fig. 20 a. The same results obtained by using the proposed procedure of conjugate smoothing are presented in Fig. 20 b.

a b

Fig. 20. Composite isoclinic patterns for second eigenmode obtained by using the procedure of conjugate approximation (a) and by using the proposed procedure of conjugate smoothing (b)

From the presented results the applicability of the proposed procedure of conjugate smoothing is evident. The performed investigations indicate that the composite isoclinic patterns with isoclinics for various directions of the vector of polarization in a plane polariscope are important for the interpretation of the stress fields obtained in photo-elastic measurements.

Research of distribution of stresses in separate relief elements of polymeric material

When reading, the blind people touch the relief elements, which causes the static and dynamic behaviour. The wear begins in the areas where the highest level of stresses exist, therefore the prediction of material wear over time is important.

The stresses of nodal points are calculated using conjugate approximation method. Equivalent stresses are represented by intensity of the image.

Numerical procedure

x, *y* and *z* denote the axes of the system of coordinates. Nodal values of the stresses are determined from:

$$\left[\hat{K}\right]\left[\{\delta_x\} \quad \{\delta_y\} \quad \{\delta_z\} \quad \{\delta_{xy}\}\right]=\left[\hat{F}\right], \tag{1}$$

where $\{\delta_x\}$, $\{\delta_y\}$, $\{\delta_z\}$, $\{\delta_{xy}\}$ are the vectors of nodal values of the stresses σ_x, σ_y, σ_z, τ_{xy} are the vectors of nodal values of the stresses:

$$\left[\hat{K}\right]=\int\left[\hat{N}\right]^T\left[\hat{N}\right]dxdy, \tag{2}$$

$$\left[\hat{F}\right]=\int\left[\hat{N}\right]^T\left[\sigma_x \quad \sigma_y \quad \sigma_z \quad \tau_{xy}\right]dxdy, \tag{3}$$

where:

$$\left[\hat{N}\right]=\left[N_1 \quad N_2 \quad \dots \quad N_9\right], \tag{4}$$

where N_1, N_2, …, N_9 are the shape functions of the two dimensional Lagrange quadratic finite element. Stresses in the expression of $\left[\hat{F}\right]$ are determined from:

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \tau_{xy}\end{Bmatrix}=[D][B]\{\delta\}, \tag{5}$$

where $\{\delta\}$ is the vector of nodal displacements, $[B]$ is the matrix relating strains with displacements and $[D]$ is determined as:

$$[D]=\begin{bmatrix}K+\frac{4}{3}G & K-\frac{2}{3}G & 0\\ K-\frac{2}{3}G & K+\frac{4}{3}G & 0\\ K-\frac{2}{3}G & K-\frac{2}{3}G & 0\\ 0 & 0 & G\end{bmatrix}, \tag{6}$$

where $K = \dfrac{E}{3(1-2\nu)}$ ir $G = \dfrac{E}{2(1+\nu)}$. In the latter expressions E is modulus of elasticity and ν is Poisson's ratio.

Equivalent stress is determined as:

$$I = \sqrt{\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 + 6\tau_{xy}{}^2}. \tag{7}$$

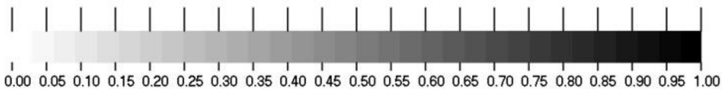
Investigation of the stress field for half of a circle

It is assumed that the mechanical system with Braille consists of one row of elements located on one half of a circle with radius of the middle line 0.001 m and semi thickness 0.0001 m (see Fig. 21).

Static problem

Equivalent stresses are presented in Fig. 21 a. Black colour of the images corresponds to the highest values of equivalent stress, white color – to the lowest values of equivalent stress. A grey scale bar is presented in Fig. 21 b.

a



b

Fig. 21. Equivalent stresses (a) and grey scale bar (b)

Eigenmodes

The equivalent stresses of the first and fourth eigenmodes are presented in Fig 22.

a

b

Fig. 22. Equivalent stresses the first eigenmode (a), the fourth eigenmode (b)

From the findings of eigenmodes it was obtained that the complexity of stress distribution increases with the increasing of eigenmode number and the highest stresses are at the surface of material (we can see that the first eigenmode along the BR element is 3 nodes, the fourth – 6). It has also shown that the equivalent stresses are highest on the surface top, that is, the darkest areas are at the surface top.

Investigation of the stress field for the structure with a straight part

In this chapter, relief elements with a straight part are investigated. The system with Braille consists of one row of elements located on one fourth of a circle, of a straight part with the length equal to the length of the middle line of half of a circle and of another one fourth of a circle.

Eigenmodes

The equivalent stresses of the first and fourth eigenmodes are presented in Fig 23.

We have obtained that the complexity of stress distribution in general increases with the increase of the number of the eigenmode (the first form along the BR element is 4 nodes, the fourth – 6). Maximum values of equivalent stress are usually at the surfaces of the Braille, that is, the darkest areas are at the surface top.

a b

Fig. 23. Equivalent stress a) the first eigenmode, b) the fourth eigenmode

Experimental tests have indicated that Braille dots experience degradation of strength of material at the top because of frequent contacts with fingers or other materials, thus in terms of strength, Braille dots and relief elements with a flat top of surface are more advantageous.

Research of distribution of stresses in Braille dots of polymeric material

Investigation on the axisymmetric model

Separate Braille elements are analyzed by using an axisymmetric model. Nodal stresses are calculated by using the procedure of conjugate approximation. Equivalent stresses are represented by the intensity of the image.

Numerical procedure

In the mathematical model, x denotes the radial coordinate, y – the axial coordinate, z – the coordinate in the angular direction. Nodal values of the stresses are determined from:

$$\left[\hat{K}\right]\left[\{\delta_x\} \quad \{\delta_y\} \quad \{\delta_z\} \quad \{\delta_{xy}\}\right]=\left[\hat{F}\right], \qquad (8)$$

where $\{\delta_x\}$, $\{\delta_y\}$, $\{\delta_z\}$, $\{\delta_{xy}\}$ are the vectors of nodal values of the stresses σ_x, σ_y, σ_z, τ_{xy} and:

$$\left[\hat{K}\right] = \int \left[\hat{N}\right]^T \left[\hat{N}\right] 2\pi x dx dy, \qquad (9)$$

$$\left[\hat{F}\right] = \int \left[\hat{N}\right]^T \left[\sigma_x \quad \sigma_y \quad \sigma_z \quad \tau_{xy}\right] 2\pi x dx dy, \qquad (10)$$

where $\left[\hat{N}\right]$ is the row of the shape functions N_1, N_2, …, N_9 of the two dimensional Lagrange quadratic finite element.

Stresses in the expression of $\left[\hat{F}\right]$ are determined from:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \end{Bmatrix} = [D][B]\{\delta\}, \qquad (11)$$

where $\{\delta\}$ is the vector of nodal displacements, $[D]$ is the matrix of elastic constants and $[B]$ is determined as:

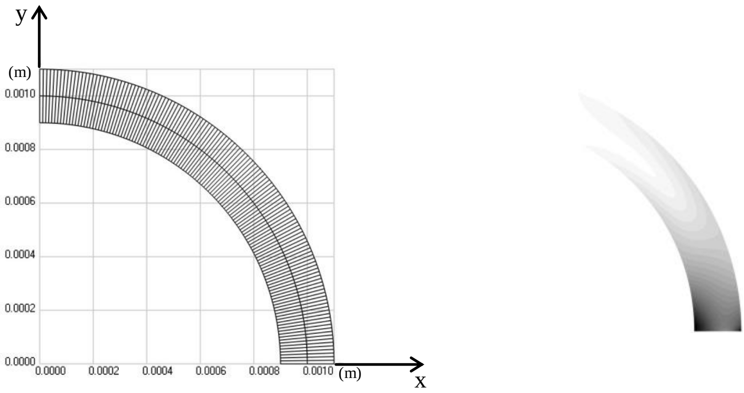
$$[B] = \begin{bmatrix} \frac{\partial N_1}{\partial x} & 0 & \dots \\ 0 & \frac{\partial N_1}{\partial y} & \dots \\ \frac{N_1}{x} & 0 & \dots \\ \frac{\partial N_1}{\partial y} & \frac{\partial N_1}{\partial x} & \dots \end{bmatrix}. \qquad (12)$$

Equivalent stresses are calculated the same as the plane strain problem (see. 7 formula).

Research of stress field of orbicularBraille dots

It is assumed that Braille consists of one row of elements located on one fourth of a circle with radius of the middle line 0.001 m and semi thickness 0.0001 m.

The left end of the structure coincides with the axis of symmetry. 64 two dimensional Lagrange quadratic finite elements are used. The finite element mesh is shown in Fig. 24 a. Equivalent stresses are presented in Fig 24 b.



a b

Fig. 24. Finite elements of Braille dots (a) and equivalent stresses (b)

The eigenmodes

The equivalent stresses of the first and fourth eigenmodes are presented in Fig. 25. From the obtained results it is seen that the complexity of stress distribution in general increases with the increase of the number of the eigenmode and that maximum values of equivalent stress are usually at the surfaces of the Braille dots i.e., the darkest areas in the images are on the surfaces.

a b

Fig. 25. Equivalent stress a) the first eigenmode, b) the fourth eigenmode

Investigation of the stress field for the Braille with an improved element

It is assumed that Braille consists of one row of elements located on a straight part with the length equal to the length of the middle line of one fourth of a circle and then of one fourth of a circle. The radius of the middle line of the part of the circle is 0.001 m and semi thickness of the structure is 0.0001 m.

The static problem

Equivalent stresses are presented in Fig. 26 a. Maximum equivalent stress usually takes place at the surfaces of the Braille and tactile relief element. In order to be able to interpret the values of equivalent stress on the lower and upper surfaces of the Braille and tactile relief element a graphical representation is desirable. Equivalent stresses on the lower and upper surfaces represented in the normal direction to the surfaces are presented in Fig. 26 b.

Fig. 26. Equivalent stresses (a) and equivalent stresses on the lower and upper surfaces (b)

The eigenmodes

The equivalent stresses of the first and fourth eigenmodes are presented in Fig. 27 a, b. Equivalent stresses on the lower and upper surfaces represented in the normal direction to the surfaces are presented in Fig. 27 c, d.

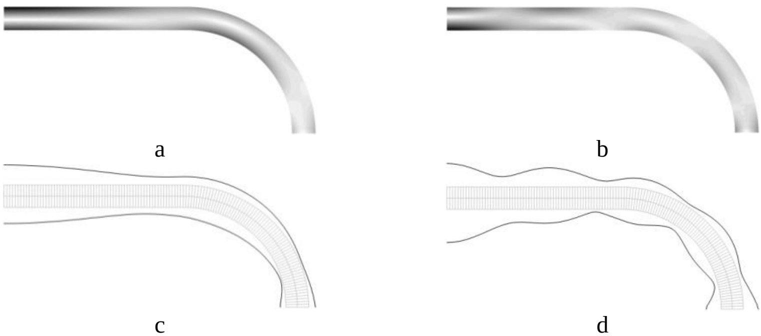


Fig. 27. Equivalent stresses a) the first eigenmode, b) the fourth eigenmode and equivalent stresses on the lower and upper surfaces represented in the normal direction c) the first, d) the fourth eigenmode

We can see that usually the equivalent stresses are highest on the surface of Braille dots i.e., the darkest areas in the images are on the surfaces.

The numerical studies have shown that Braille dots undergo the decrease of strength in their upper parts due to frequent contact with fingers or other materials (e.g., when the Braille pages are bonded), thus in terms of resistance Braille dots or relief elements with a flat upper part of the surface are more advantageous.

Research of stresses in Braille dots according to axissymmetric model for the first harmonic

The numerical procedure is based on the formulation of the axisymmetric problem for the first harmonic.

A separate Braille element is analyzed. An axisymmetric problem for the first harmonic in the circumferential direction is investigated. Maximum equivalent stresses on the circles on the boundaries of the structure for the first eigenmodes are obtained.

Numerical procedure

Further *x* denotes the radial coordinate, *y* – the axial coordinate and *z* – the coordinate in the angular direction, while θ denotes the angle of the system of coordinates. Equivalent stress is determined as:

$$I=\sqrt{\left(\sigma_x-\sigma_y\right)^2+\left(\sigma_y-\sigma_z\right)^2+\left(\sigma_z-\sigma_x\right)^2+6\tau_{xy}{}^2+6\tau_{yz}{}^2+6\tau_{zx}{}^2}, \quad (13)$$

where σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx} is the stresses.

For the investigated problem:

$$I=\sqrt{A\cos^2\theta+B\sin^2\theta}=\sqrt{A+\left(B-A\right)\sin^2\theta}, \quad (14)$$

where:

$$A=\left(\sigma_x^c-\sigma_y^c\right)^2+\left(\sigma_y^c-\sigma_z^c\right)^2+\left(\sigma_z^c-\sigma_x^c\right)^2+6\tau_{xy}^{c\ 2},\ B=6\tau_{yz}^{s\ 2}+6\tau_{zx}^{s\ 2}, \quad (15)$$

where the superscripts *c* and *s* denote the cos and sin amplitudes of the stresses. Thus the maximum equivalent stress on a circle is determined from:

$$I_{\max}=\sqrt{\max\left(A,B\right)}. \quad (16)$$

Investigation of the stress field for the Braille circular field

The radius of the middle line of the part of the circle is 0.001 m and semi thickness of the structure is 0.0001 m. The left end of the Braille dot coincides with the axis of symmetry. All amplitudes of displacements of the three nodes on both ends of the structure are assumed equal to zero. Maximum equivalent stresses on circles on the boundaries of the structure for the first eigenmodes are presented in Fig. 28. Equivalent stresses on the surfaces are represented graphically in the normal direction to the boundaries of the structure.

From experimental investigations it can be noticed that deterioration of the quality of polymeric material usually starts from the surfaces of the investigated sample. This indicates that the results of equivalent stress on the surfaces of polymeric film are of special importance. At the places of maximum equivalent stress defects in the material usually start to develop after a number of cycles of loading.

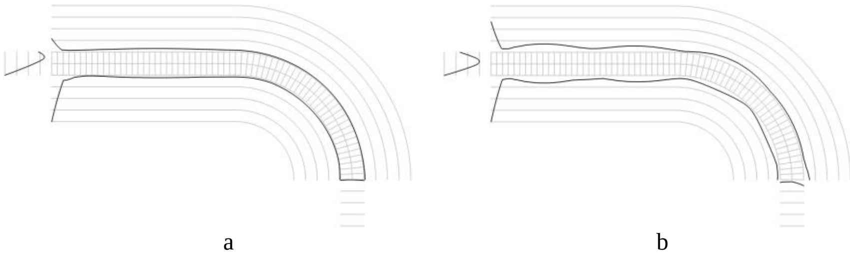


Fig. 28. Maximum equivalent stresses on circles on the boundaries for a) the first, b) the fhourte eigenmodes

Determination of cycles of vibrating polymeric film to the start of wear

The finite element has one nodal degree of freedom, the displacement in the direction of *x* axis. Eigenmodes are calculated and then the distribution of the longitudinal stress σ_x in the polymeric film in the status of maximum displacement according to the eigenmode for each eigenmode is determined. The number of cycles till the start of wear is calculated as: $N = \frac{C}{|\sigma_x|^m}$.

Results of analysis of cycles to the start of wear

The length of the analyzed structure is 0.2 m. On the left and the right ends of the structure the displacements are equal to zero. It is assumed that the value of the parameter $C = 10^5$. The values of parameter m are assumed from $m = 0.4$ up to $m = 4$. The fourth eigenmode is investigated. Stresses are presented in Fig. 29 a, numbers of cycles till the start of wear in Fig. 29 b.

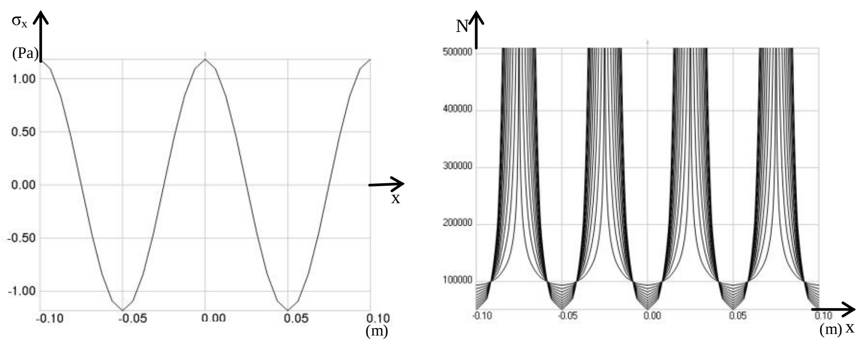


Fig. 29. The fourth eigenmode: a) stresses, b) numbers of cycles till the start of wear

From the presented model for determining the number of cycles of loading till the start of wear, it is clear that the presented drawings are applicable in experimental determination of the parameters of the model. This follows from the fact that the value of *C* changes only the scale of *y* axis in the graphical relationships describing the numbers of cycles till the start of wear and the relationships for a number of typical values of the parameter *m* are presented.

CONCLUSSIONS

1. The review of literature sources has shownd that there is a lack of studies providing the experimental and numerical research of stability of main Braille dots parameters formed using different materials and printing types under the effect of climatic and performance factors on Braille printouts.
2. It was determined that each separate geometrical parameter of Braille dot (height, diameter, distance between dots) and also the entirety of them have an important meaning to the readability of blind people. Also with the increasing age of respondents (60 years old and older) Braille is hard to read at 0.1 mm and lower height due the inappropriately formed geometry of dots.
3. Microscopic analysis, methods of inks thermal analysis, photoelasticity methods for stresses determination, data statistical analysis and FEM were used in carrying out the research. The methods of microscopic analysis allowed us to carry out the qualitative analysis of Braille dots surface under mechanical effect (abrasion), temperature factors and ageing. The suitability of screen printing inks composition was determined by using the thermal analysis method. The distribution of stresses was determined in Braille printouts using the photoelasticity method.
4. During the research it was determined that under the effect of mechanical impact, temperature factors and ageing, the decreasing value of Braille dots is different depending on Braille forming type and used materials. Braille formed using embossing is least durable because relief elements change their geometrical parameters and the information on the packages becomes unreadable for the blind people. Braille dots formed using embossing on paperboard Multicolor Mirabel are least durable under mechanical impact (increase is 31%). The screen printing and plastisolic inks are most suitable to print Braille on textile, Munken Pure paper, Multicolor Mirabel paperboard because Braille dots remain less changed under mechanical impact.
5. Optimal printing regimes were determined allowing to form Braille dots of appropriate size using digital printing (printing velocity v = 0.58 m/s, varnish temperature t = 59 °C, varnish pressure $P = 2.5\times10^5$ Pa). The suitability of inks for Braille forming using screen printing was determined applying the methods of thermal analysis. Braille dots of 0.20 mm height could be formed using screen printing inks with thermo powder and curing them at optimal working temperature range 98–198 C.

6. It was determined that in polymeric products with Braille, residual stresses are forming that decrease the durability of such products. It was determined that the highest stresses form in the areas of Braille and relief elements forming.
7. The results of stress distribution were related by applying the numerical model. The obtained results of simulation show that the highest stresses are on the surface of Braille dot. Considering the fact that Braille dots with flat surface are more advantageous in practical application, they were investigated in more detail. Graphic images of equivalent stress in the upper and lower surfaces were obtained that allow to determine the areas with the highest values of equivalent stress. The research has shown that the complexity of stress distribution increases with the increasing number of eigenmode.
8. Numerical research and experimental tests of photoelasticity complement each other and enable to interpret the stress fields in polymeric materials. The obtained findings are used for improving the design of packages, labels with Braille and relief elements. The methodology was expanded during numerical research and using FEM models that give a possibility to assess the distributions of stresses of polymeric materials with Braille and relief elements.

LIST OF PUBLICATIONS ON THE THEME OF THE DISSERTATION

Articles in scientific publications from international databases

In publications of „ISI Web of Science“ Database of the Institute of Scientific Information with citation index

1. Havenko, Svetlana; Labetska, Marta; Stępień, Krzysztof; Kibirkštis, Edmundas; Venytė, Ingrida. Research of influencing factors on the change of geometric parameters of Braille elements on self-adhesive labels // Mechanika / Kauno technologijos universitetas, Lietuvos mokslų akademija, Vilniaus Gedimino technikos universitetas. Kaunas: KTU. ISSN 1392-1207. 2013, T. 19, nr. 6, p. 716-721. DOI: 10.5755/j01.mech.19.6.6016. [Science Citation Index Expanded (Web of Science); INSPEC; Compendex; Academic Search Complete; FLUIDEX; Scopus]. [IF: 0,336, AIF: 1,740 (E, 2013)].
2. Venytė, Ingrida; Kibirkštis, Edmundas; Voloshin, A.; Ragulskis, Kazimieras; Paškevičius, Petras; Sudintas, Antanas Rimantas; Ragulskis, Liutauras. Investigation of stresses during dynamic behavior of polymeric films used for Braille // Journal of Vibroengineering / Vibromechanika, Lithuanian Academy of Sciences, Kaunas University of Technology, Vilnius Gediminas Technical University. Kaunas: Vibroengineering. ISSN 1392-8716. 2014, Vol. 16, no. 3, p. 1248-1257. [Science Citation Index Expanded (Web of Science); INSPEC; Academic Search Complete;

Central & Eastern European Academic Source (CEEAS); Computers & Applied Sciences Complete; Current Abstracts; TOC Premier]. [IF: 0,660, AIF: 2,218 (E, 2013)].

3. Venytė, Ingrida; Kibirkštis, Edmundas; Mayik, Volodymyr; Dudok, Taras; Vasylkiv, Yuriy. Investigation of resistance to mechanical effect of Braille formed on different materials // Materials science = Medžiagotyra / Kaunas University of Technology, Academy of Sciences of Lithuania. Kaunas : KTU. ISSN 1392-1320. 2014, Vol. 20, no. 2, p. 183-188. DOI: 10.5755/j01.ms.20.2.3039. [Science Citation Index Expanded (Web of Science); INSPEC; Scopus]. [IF: 0,336, AIF: 3,530 (E, 2013)].
4. Venytė, Ingrida; Kibirkštis, Edmundas; Voloshin, A.; Ragulskis, Kazimieras; Ragulskis, Liutauras. Measurement of stresses in polymeric films with Braille and tactile elements // Journal of Vibroengineering / Vibromechanika, Lithuanian Academy of Sciences, Kaunas University of Technology, Vilnius Gediminas Technical University. Kaunas: Vibroengineering. ISSN 1392-8716. 2014, Vol. 16, no. 7, p. 3489-3497. [Science Citation Index Expanded (Web of Science); INSPEC; Academic Search Complete; Central & Eastern European Academic Source (CEEAS); Computers & Applied Sciences Complete; Current Abstracts; TOC Premier]. [IF: 0,660, AIF: 2,218 (E, 2013)].

In publications of „ISI Web of Science“ Database of the Institute of Scientific Information without citation index

1. Kibirkštis, Edmundas; Venytė, Ingrida; Mayik, Volodymyr; Vakulich, Diana. Investigation of geometrical and` physical – mechanical parameters of Braille by assessing the different types of cardboard materials // Mechanika / Kauno technologijos universitetas, Lietuvos mokslų akademija, Vilniaus Gedimino technikos universitetas. Kaunas: Technologija. ISSN 1392-1207. 2011, T. 17, nr. 6, p. 656-660. [Science Citation Index Expanded (Web of Science); INSPEC; Compendex; Academic Search Complete; FLUIDEX; Scopus].

Articles in other reviewed scientific publications

1. Miliūnas, Valdas; Kibirkštis, Edmundas; Ragulskis, Kazimieras; Paškevičius, Petras; Ragulskis, Liutauras; Voloshin, A.; Venytė, Ingrida. Measurement of stresses in a vibrating polymeric film // Journal of measurements in engineering (JME) / Lithuanian Academy of Sciences, Kaunas University of Technology, Vilnius Gediminas Technical University. Kaunas : Vibroengineering. ISSN 2335-2124. 2014, Vol. 2, no. 2, p. 122-129.

OTHER PUBLICATIONS

1. Havenko, Svitlana; Kochubei, Victoriia; Labetska, Marta; Khadzhynova, Svitlana; Kibirkštis, Edmundas; Venytė, Ingrida. Brailio rašto, suformuoto tradicine trafaretine spauda ir dažais su termo milteliais, terminė analizė // Medžiagų inžinerija 2013 : respublikinė konferencija : konferencijos pranešimų santraukos, 2013 m. lapkričio 15 d, Kaunas / Kauno technologijos universitetas, Lietuvos medžiagų tyrinėtojų asociacija. Kaunas : Technologija. ISSN 2345-0886. 2013, p. 71.
2. Kibirkštis, Edmundas; Venytė, Ingrida; Lydekaitytė, Justina. Resistance to mechanical effect of Braille dot surface, formed on different materials // Кваліологія книги : VII міжнародна науково-практична конференція, 6-8 червня 2012 року : матеріали конференції. Львів: УАД, 2012. p. 144-150.
3. Venytė, Ingrida; Kibirkštis, Edmundas; Vaitasius, Kęstutis. Investigation of braille parameters // Пакувальна індустрія : сучасні тенденції розвитку та підготовка кадрів : І міжнародна науково-практична конференция, 8-9 листопада 2012, Львів [Україна] : матеріали конференції. Львів : МОНМСУ, 2012. p. 72-74.
4. Venytė, Ingrida; Kibirkštis, Edmundas. Brailio rašto, suformuoto ant skirtingų medžiagų, kokybinių parametrų tyrimai // Medžiagų inžinerija 2012 : respublikinė konferencija : konferencijos pranešimų santraukos, 2012 m. lapkričio 16 d, Kaunas / Kauno technologijos universitetas, Lietuvos medžiagų tyrinėtojų asociacija. Kaunas : Technologija, 2012. ISBN 9786090207505. p. 49.
5. Kibirkštis, Edmundas; Venytė, Ingrida; Mayik, Volodymyr; Vakulich, Diana. Investigation of geometrical and physical-mechanical parameters of Braille by assessing materials // Mechatronic Systems and Materials : abstracts of the 7th international conference MSM 2011, 7-9 July 2011, Kaunas University of Technology, Kaunas (Lithuania) / Kaunas University of Technology, Vilnius Gediminas Technical University, Opole University of Technology, Bialystok Technical University. Kaunas : Technologija. ISSN 1822-8283. 2011, p. 82-83.
6. Venytė, Ingrida; Miliūnas, Valdas; Kibirkštis, Edmundas. Research of theoefficient of friction of the varnished paperboard // Кваліологія книги : ІІІ міжнародна науково-практична конференція студентів, магистрантів та аспрантів : матеріали конференції / Міністерство освіти і науки України, Українська академія друкарства, Студентське наукове товариство. Львів : Українська академія друкарства, 2014. p. 70-75.

BRIEF INFORMATION ABOUT THE AUTHOR

Personal information:

Ingrida Venytė was born on the 22[th] of Septemper 1977 in Kaunas, Lithuania.

Education:

1995 graduated from Kaunas Julijanavos secondary school.
1995 – 1999 studied at Kaunas University of Technology, Faculty of Mechanical Engineering and was granted Mechanical engineering bachelor's degree.
1999 – 2000 studied at Kaunas University of Technology, Faculty of Design and Technologies and was granted Polygraphy technology engineer's degree.
2005 – 2008 studied at Kaunas University of Technology, Faculty of Design and Technologies, Department of Graphic Communications Engineering and was granted Industrial engineering master's degree (Diploma with Honours).
2010 – 2014 doctoral studies in the field of Materials Engineering Sciences at Kaunas University of Technology, Faculty of Design and Technologies, Department of Graphic Communications Engineering (since 01.09.2013 Faculty of Mechanical Engineering ant Design, Department of Production Engineering).

Work experience:

11.09.2000 – 30.06.2001 part-time lecturer, Laboratory of the Polygraphy Engineering Science, Faculty of Mechanical Engineering, Kaunas University of Technology.
16.10.2000 – 28.12.2000 laboratory assistant, Science Laboratory of the Printing Engineering, Faculty of Design and Technologies, Kaunas University of Technology.
09.04.2001 – 31.01.2010 junior lecturer, Faculty of Design and Technologies, Department of Graphics Communication Engineering, Kaunas University of Technology.
01.02.2010 – 31.12.2013 lecturer, Faculty of Design and Technologies, Department of Graphics Communication Engineering, Kaunas University of Technology.
Since 01.01.2014 lecturer, Faculty of Mechanical Engineering and Design, Department Production Engineering, Kaunas University of Technology.

Research interests:

Research of mechanical characteristics and properties of packages and their materials; Braille and relief element printing technologies; investigation of Braille and relief element formed on different materials; investigation of geometrical and physical – mechanical parameters of Braille.

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REZIUMĖ

Nors pastaraisiais metais informacijos perdavimo priemonės akliesiems sparčiai tobulėja, tačiau ir šiandien viena iš svarbiausių priemonių yra Brailio raštas (BR). Šiuo metu Lietuvoje BR plačiausiai yra naudojamas kartoninėse pakuotėse, jį suformuojant įspaudimo būdu. Reljefiniams elementams formuoti gali būti taikomi ir kt. iškilių elementų formavimo būdai, t.y. trafaretinė spauda, termografija, skaitmeninė rašalinė spauda ir kt. Brailio raštą tikslinga naudoti ne tik vaistų pakuotėms, bet ir kitos paskirties prekėms – maisto, drabužių, chemijos gaminių pakuotėms ir etiketėms iš skirtingų medžiagų (polimero, tekstilės, folijos, metalo, stiklo ir kt.), naudojant iškilių elementų formavimo technologijas. Šių spaudos būdų tyrimai išplečia BR naudojimo galimybes.

Darbe atlikti tyrimai įvertino Brailio rašto taškų ir reljefinių elementų fizikinių-mechaninių parametrų stabilumą, esant skirtingoms medžiagoms, BR formavimo būdui ir eksploatacinėms sąlygoms.

Darbe ištirti BR taškų geometriniai ir fizikiniai parametrai, panaudojant specialius dažus ir laką. Ištirtos BR spausdinimui tinkamos medžiagos ir optimalūs spausdinimo technologiniai parametrai. Nustatytas polimeriniuose gaminiuose su BR ir reljefiniais elementais įtempių pasiskirstymas, kas turi tiesioginės įtakos galutinei gaminių kokybei.

Tyrimams atlikti buvo naudojama mikroskopinė analizė, dažų terminės analizės metodas, įtempių nustatymo fototamprumo metodas, duomenų statistinė analizė, o taip pat ir BEM. Mikroskopinės analizės metodas leido atlikti BR taškų paviršiaus kokybinę analizę, veikiant mechaniniam poveikiui, temperatūriniams veiksniams, senėjimui. Atlikus matematinę-statistinę analizę nustatyta technologinių faktorių įtaka BR geometriniams parametrams, parinkti optimalūs skaitmeninio spausdinimo režimai. Terminės analizės metodu buvo nustatytas trafaretine spauda naudojamų dažų kompozicijos tinkamumas. Fototamprumo metodu, atspauduose su BR, ištirtas įtempių pasiskirstymas. Skaitmeninių tyrimų metu, pasinaudojant BEM modeliais, praplėsta metodologija, leidžianti įvertinti polimerinių medžiagų su BR ir reljefiniais elementais įtempių pasiskirstymus. Skaitmeniniai tyrimai ir fototamprumo eksperimentai papildo vienas kitą ir įgalina išsamiai interpretuoti įtempių laukus polimerinėse medžiagose. Gautieji rezultatai gali būti naudojami tobulinant pakuočių, etikečių su Brailio raštu ir reljefiniais elementais projektavimą.

Tyrimų pagrindu išplėsta Brailio rašto (BR) ir reljefinių elementų taikymo sritis, kas leidžia regėjimo negalią turinčius asmenis labiau integruoti į visuomenę.

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