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Structural integrity verification of polycarbonate type personal identity documents

S. Greičius*, V. Daniulaitis, R. Vasiliauskas***, K. Pilkauskas****, V. Jūrėnas*******

**Mykolas Romeris University, Kaunas Faculty of Public Security, V. Putvinskio 70, 44211 Kaunas, Lithuania, E-mail: s.greicius@mruni.eu*

***Kaunas University of Technology, Studentų g. 50, 51368 Kaunas, Lithuania, E-mail: vytautas.daniulaitis@ktu.lt*

****Mykolas Romeris University, Kaunas Faculty of Public Security, V. Putvinskio 70, 44211 Kaunas, Lithuania, E-mail: r.vasiliauskas@mruni.eu*

*****Kaunas University of Technology, Mickevičiaus 37, 44244 Kaunas, Lithuania, E-mail: kestutis.pilkauskas@ktu.lt*

******Kaunas University of Technology, Mechatronics Center for Research, Kęstučio str. 27, 44312 Kaunas, Lithuania, E-mail: v.jurenas@ktu.lt*

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1. Introduction

As Lithuania has joined the Schengen area and due to the fact that it has external borders of the area, officers of the State Border Guard Service must take great responsibility in allowing or not allowing individuals to enter not only to their own country, but the whole Schengen area as well. Rapid globalization and integration processes lead to a growing number of persons crossing the borders. In particular, the flows of individuals crossing the borders increase in the events of emergencies and moving across the borders is a common problem of all the institutions involved in border control activities. Therefore, reliable authenticity assessment of personal identity documents is a prerequisite for normal existence of a human in the infrastructure of modern society.

According Schengen Borders Code [1] ”all persons shall undergo a minimum check in order to establish their identities on the basis of production or presentation of their travel documents. Such a minimum check shall consist of a rapid and straightforward verification, where appropriate by using technical devices and by checking, in the relevant databases, information exclusively on stolen, misappropriated, lost and invalidated documents, of the validity of the document authorizing the legimate holder to cross the border and of the presence of signs of falsification or counterfeiting“.

The officers, who inspect travel documents of persons crossing the borders, should be familiar with the procedures of manufacture, issuance and application of the documents as well as anti-counterfeiting techniques. In practice, a number of methods are used for protection of personal identity documents against counterfeiting and a number of methods of assessing their authenticity are applied. For protection of the documents can be applied different means – rainbow press (three color protection grids, microtexts and other), special paint (optically variable, shining under UV or infrared illumination, having magnetic, electrical conductive, temperature sensitive or chemical properties or other), special printing methods (intaglio printing, letterpress, metallographic, laser printing, etc.), the paper of specific quality and with distinctive features (watermarks, filaments, shining or nonshining under the appropriate illumination, etc), new materials (polymers, teslin, multilayer polycarbonate structures and other).

In order to ensure smooth movement of persons, document checking procedures are to be reduced significantly in time. Usually for inspection of the document (validity assessment, visa) only a few minutes are allocated. In case of suspicion on the authenticity of the document, it is inspected not only visually, but using technical devices as well. With the evolution of manufacturing technologies of travel documents, and materials used for the manufacture, as a very important factor becomes the development and application of new devices and new methods which allow to verify the document‘s authenticity.

In order to ensure smooth movement of persons crossing the borders personal travel documents of European Union countries and majority of the countries of the world are being developed taking into account the requirements of EU and recommendations of the International Civil Aviation Organization (ICAO). Also they should comply the requirements of standard ISO/IEC 7810:1995 for ID-3 cards and the requirements defined in the document Doc9303 of the International Civil Aviation Organization (ICAO) as well as in COUNCIL REGULATION (EC) No 2252/2004 of 13 December 2004 on standards for security features and biometrics in passports and travel documents issued by Member States [2]. The main requirements to data sheet of the document (the main object of counterfeit) are set on its thickness (it should not exceed 0.9 mm) and on the material from which it is manufactured (nowadays the most frequently a multilayer structure made of polycarbonate foil and other synthetic materials is used). Typical structure of a document sheet which is composed of several layers of polycarbonate foil Makrofol ID 6-2 laserable, Makrofol ID 4-4 white [3], manufactured by the German company Bayer Material Science AG and a layer of synthetic material is presented in Fig. 1.

Attention should be paid to the fact that the structure as presented is just typical (recommended) structure. In the countries that currently apply multilayer structures for their travel documents (USA, majority of European countries, the countries of South-East Asia, Central and South America, Africa) the data sheets are manufactured from different number of polycarbonate foil layers each of which has different thickness integrating these layers with a layer of teslin (synthetic material based on silicon oxide) – as presented in Fig. 2.

Statistical analysis of the results on authenticity assessment of personal identity documents reveals that data sheets most frequently are damaged (with the aim to counterfeit) by mechanical means in the zone of photo. After damaging of the data sheet in case of counterfeit and putting efforts to restore its initial state, always residual technological defects remain (joining of polycarbonate foil layers and teslin layer by fusion or applying gluing materials and other). In Fig. 3 an example of the data sheet which was mechanically damaged with the sequent efforts to restore its primary state is presented.

For authenticity assessment of the travel documents various methods of nondestructive control can be applied. They are based on different principles and differ by sophistication level of the hardware and software applied [4-6]. As the methods applied, the methods of visual inspection, laser, ultrasonic, acoustic emission, vibration methods, mechanical loading, thermo graphic, thermal emission and other methods can be applied [7, 8].

Taking into account specific features of the data sheet manufacturing technology (fusion of the layers and/or gluing), the present research is based on the assumed hypothesis – after mechanical damaging of the document’s structure with the following attempts to restore its primary state the existence of residual mechanically damaged zones (air bubbles – gaps, lack or excess of gluing material, melting of the layers) should have an influence on physical and mechanical properties of the structure [9-12]. The change of such properties could serve as the background for authenticity assessment of the document under inspection. In order to prove the hypothesis experimental research and simulation of the structure behavior applying thermo graphic and thermal emission methods was performed.

Fig. 1 Structure of the data sheet of a document formed of several polycarbonate foil layers

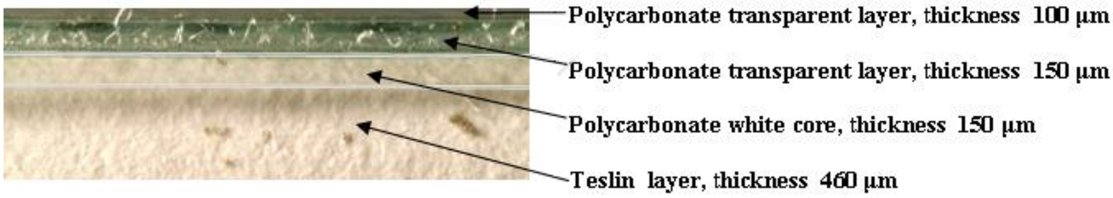

Fig. 2 Cross section image of the data sheet of a travel document used by some EU countries

Fig. 3 Image of a mechanically damaged data sheet of the document after the attempts to restore its initial state

2. Experimantal research

With the aim to make analysis of the influence of technological defects in the data sheet (delaminating of polycarbonate foil and teslin layer, locally damaged zones, inserts of non proper material) on thermal properties (e.g. thermal conductivity) experimental research of heat flux transfer in the direction of the sheet thickness was performed. An assumption that heat conductivity is different in structurally healthy and damaged zones would suggest not uniform temperature field on a surface of the sheet if its opposite surface is affected by a uniform across all the surface area heat flux.

Experimental research was performed using the test rig, the structure of which is presented in Fig. 4. As it is seen, thermo graphic camera A20 (FLIR Systems, Inc., USA) was used to capture the image of temperature fields on the sheet‘s side and numerical values of temperatures at analyzed points were recorded by infrared thermometer Testo 845 (TESTO, Inc., USA). Experimentation was carried out according the following procedure: One side of the analyzed document was affected for 120 seconds by a locally applied heat flux (diameter of the heat flux zone approximately equals to 10 mm) which was generated by a heat source of infrared radiation. Simultaneously surface temperature dynamics (change in time) on the opposite side of the document was recorded by infrared thermometer Testo. Then the heat source was removed allowing the structure to cool recording the surface temperature for 250 s from start point of the test. Together temperature isosurfaces of the relatively big area of the document‘s sheet covering the heat flux affected local zone were captured by thermo graphic camera A20 at different instances of time. Such testing procedures were performed with structurally healthy and mechanically damaged document sheets. Next, onto one side of the document sheet uniformly distributed over all the surface area heat flux was applied. Practically this was executed by bringing into touch contact with the sheet’s surface a uniformly heated massive body. In the later testing case temperature isosurfaces were captured by thermo graphic camera A20 as well. Structurally healthy and mechanically damaged document sheets were tested. It is worth paying attention that in case of mechanically damaged sheets temperature isosurfaces indicate not uniform temperature field on the surface.

Results of the experimental research are given in Figs. 5 and 6. In Fig. 6 examples of temperature change curves, characteristic for structurally healthy and mechanically damaged documents in case when ambient temperature was equal to 20.5°C, the document was affected by locally applied heat flux for 120 s and then allowed to cool to ambient temperature, are presented. Fig. 5 presents the captured image of thermal field on the surface of mechanically damaged document when on its opposite side was locally applied source of infrared radiation. In this case non even distribution of temperature field can be distinguished.

The results of temperature measurement reveal that under identical conditions of external heating, temperature values and their change dynamics at different points of the surface differ what suggest different parameters of thermal conductivity at these zones.

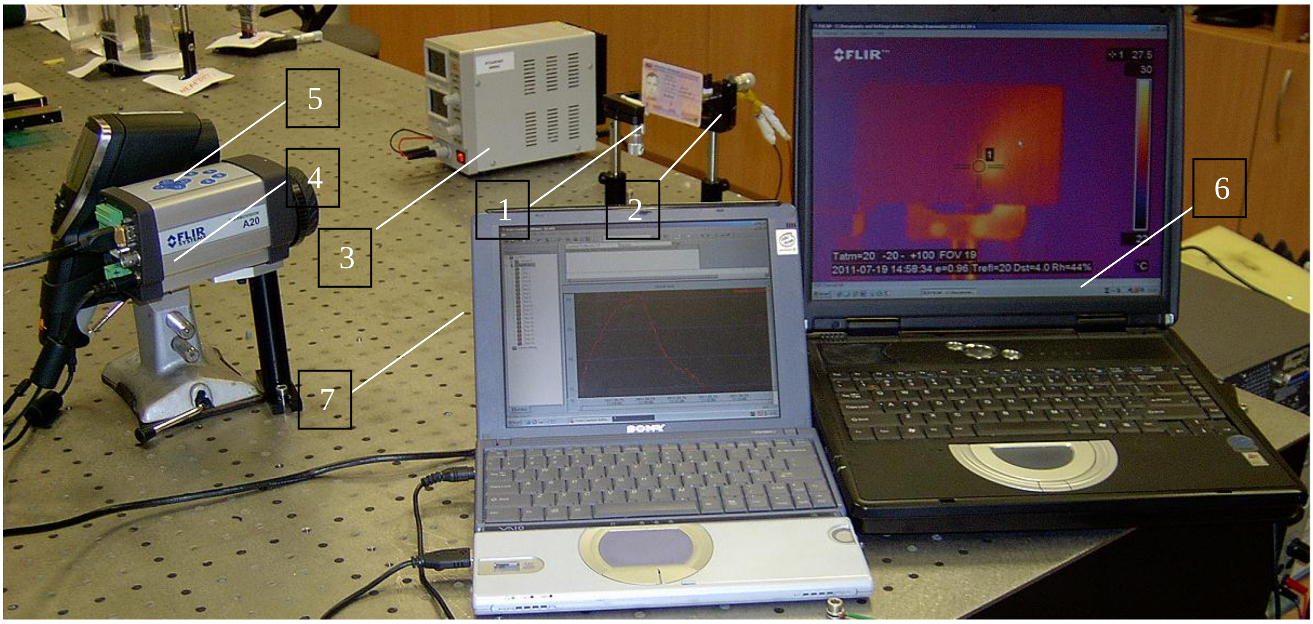

Fig. 4 Experimental stand for heating – cooling process analysis of the document‘s data sheet: *1* – data sheet of the document; *2* – source of infrared radiation; *3* – DC source HY-1803D (MASTECH, Taiwan); *4* – thermo graphic camera A20 (FLIR Systems, Inc., USA); *5* - infrared thermometer Testo 845 (TESTO, Inc., USA); *6* – PC with the installed FLIR ThermoVision software; *7* – PC with the installed TESTO Comfort SoftwareV3.4

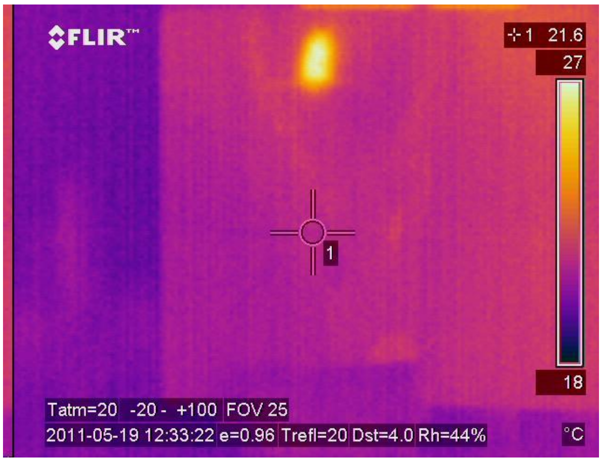

Fig. 5 Image of temperature field on the top surface of the data sheet captured by thermo vision camera in case of the application of local heating source

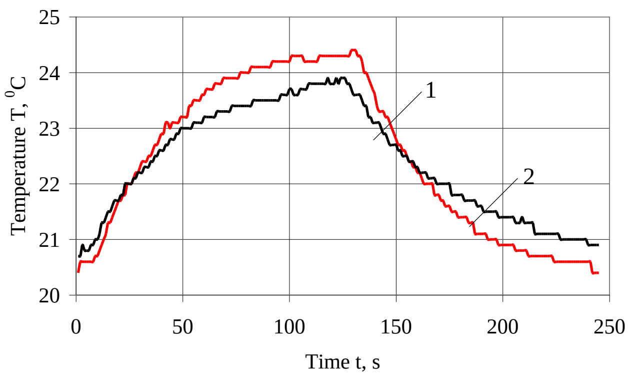

Fig. 6 Characteristic graphs of top surface temperature change in time for structurally healthy (*1*) and mechanically damaged (*2*) data sheets of travel documents

3. Theoretical analysis

Taking into account the results of performed experimantal research and with the aim to get a model describing teperature dynamics, a theoretical calculation scheme of thermal energy transfer was built as shown in Fig 7.

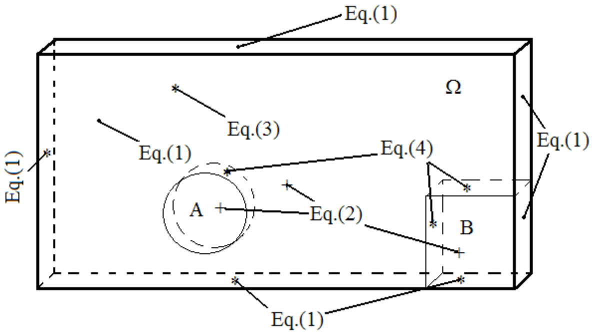

Fig. 7 Calculation scheme for the solution of heat exchange problem in the data sheet: A and B – subdomains representing mechanically damaged zones Ω – subdomain representing mechanically not damaged zone; Eq. (1) – boundary condition for all the side surfaces and the top surface; Eq. (2) – heat flux balance in all subdomains; Eq. (3) – boundary condition in the lower boundaries; Eq. (4) – boundary condition on common surfaces of subdomains

The numbers in it represent the equations for the solution of heat exchange problem as follows.

On all side surfaces and in the top surface the boundary condition – heat flux

$$-n\left(-k\nabla T\right)=q_0+h\left(T_{inf}-T\right) \tag{1}$$

The condition of heat flux balance in all subdomains

$$\rho C_p\frac{\partial T}{\partial t}+\nabla\left(-k\nabla T\right)=0 \tag{2}$$

On the bottom surface which is heat affected the boundary condition – temperature

$$T=T_0 \tag{3}$$

On common surfaces of subdomains the boundary condition – continuity

$$-n_u\left(-k_u\nabla T_u\right)-n_d\left(-k_d\nabla T_d\right)=0 \tag{4}$$

where k is thermal conductivity, k_u and k_d are out-of-plane thermal conductivity, upside and downside at the subdomains boundaries W/(mK); ρ is density, kg/m^3; n is normal vector to a surface; n_u, n_d are normal vectors to the boundaries of subdomains , upside and downside; q_0 is a inward heat flux, W/m^2; C_p is heat capacity at constant pressure, J/(kgK); h is heat transfer coefficient, W/(m^{2}K); T_{inf} is external temperature, K; T_0 is surface temperature, K; T_u, T_d are out-of-plane temperature, upside and downside on the boundaries surfaces; T is temperature K; ∇ is temperature gradient, t is time, s.

The following physical properties of materials and the parameters were used:

– Polycarbonate: k = 0.2 W/(mK); C_p = 1200 J/(kgK); ρ = 1200 kg/m^3;
– Air: k = 0.25 W/(mK); C_p = 1015 J/(kgK); ρ = 1.2 kg/m^3;
– Teslin nondamaged: k = 33 W/(mK); C_p = 550 J/(kgK); ρ = 1805 kg/m^3;
– Teslin damaged: k = 0.017 W/(mK); C_p = 600 J/(kgK); ρ = 1700 kg/m^3;
– q_0 = 0 W/m^2, h = 20 W/(m^{2}K), T_{inf} – 293.6 K.

For the solution of the problem of heat exchange FEM model implementing the presented calculation scheme was constructed using COMSOL Multiphysics system.

Physical properties of polycarbonate and air were taken from material data basis of the COMSOL Multiphysics system. Thermal properties of the damaged and nondamaged teslin layer were determined using the data obtained at experimental research presented above. Transient process analogous to the one obtained by experimentation was modeled – at the distance of 0.0005 m from the bottom plane centre of multilayer data sheet at the circular shaped area with the radius of 0.005 m 1000 W/m^2 inward heat flux was applied for the 120 s duration. Then it was removed and the data sheet was allowed to cool. The obtained results are presented in Fig. 8.

In order to analyze sensitivity of the model in detecting the defects, several defects, different in their geo-

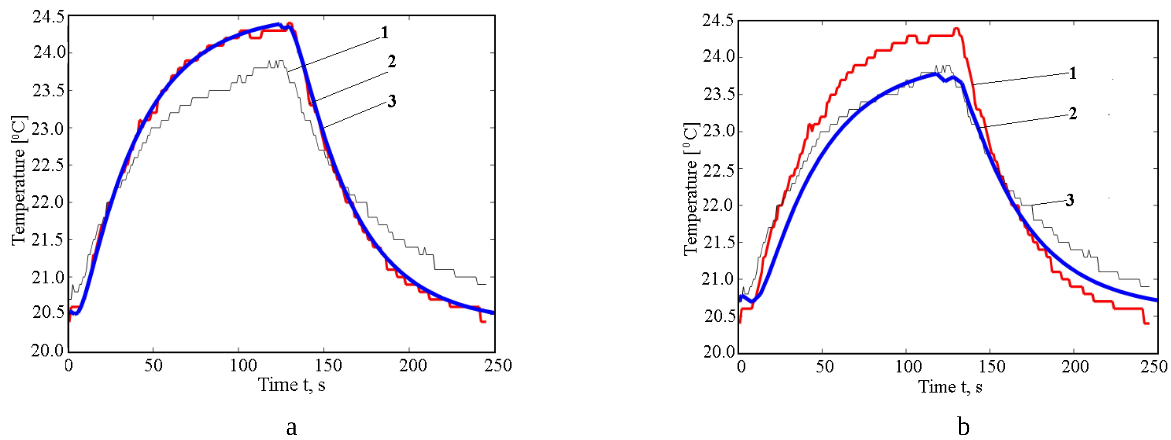

Fig. 8 Temperature variation in time in damaged (a) and non damaged (b) multilayer data sheet: *1* and *2* – experimental results *3* – simulation results

metry, dimensions and location place were introduced into the data sheet.

Simulation procedure using such data sheet is analogous like in previous experiment. Heating of the bottom surface of the data sheet was simulated by applying to it a uniform field of temperature of 27°C and constant in time at the distance of 0.0005 m from the surface. Temperature of the top surface of the sheet stabilizes after transient process of 130 s duration. The process is presented in Fig. 9.

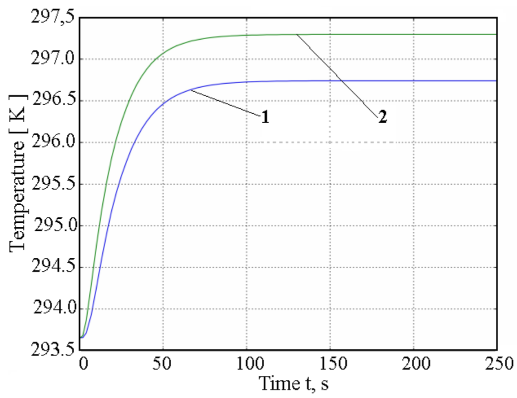

Fig. 9 Change of temperature in time on the top surface of the data sheet, when heating temperature is $T_0 = 27°C$. *1* – damaged teslin layer, *2* – nondamaged teslin layer

The simulation results in Fig. 9 indicate 0.5°C surface temperature difference of mechanically damaged and nondamaged data sheet structure. Such difference is sufficient to be registered by modern thermo vision cameras. The transient processes of surface temperature were recorded at the zones A, B and Ω (Fig. 7). Temperature field of the top polycarbonate layer of the data sheet is presented in Fig. 10. At the zones with mechanically damaged teslin layer temperatures are lower than in the zones of nondamaged structure of the data sheet. The reason is the change of thermal properties of teslin. Even the damaged zones of small dimensions can be distinguished, i.e. a circle of the diameter 0.001 m is clearly visible.

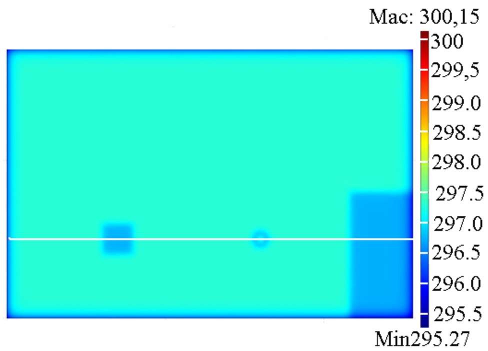

Fig. 10 Temperature field on the top of the data sheet‘s polycarbonate layer at $t = 130$ s

Temperature distribution on the top of the data sheet‘s polycarbonate layer across the section as indicated by the line in Fig. 10 is presented in Fig. 11.

From these simulation results (Fig. 11) temperature decrease on the top of the data sheet due to mechanical damage of teslin layer can be clearly seen.

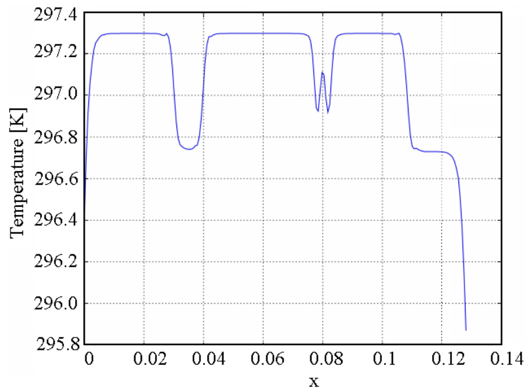

Fig. 11 Temperature distribution on the top of the data sheet‘s polycarbonate layer across the section as indicated by red line in Fig. 10 at $t = 130$ s

Temperature field can be presented in the form of temperature isosurface as given in Fig. 12.

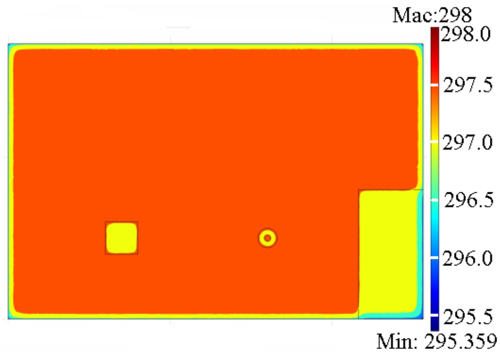

Fig. 12 Temperature isosurface at $t = 130$ s

4. Coclusions

1. The nature of mechanical damage of multilayer structure of travel documents (polycarbonate – teslin) suggests a hypothesis of the change of its physical properties in the damaged zones what serves as a background for the development of effective methods of counterfeiting detection.

2. Experimental research of the process of heat exchange through the thickness of the documents data sheet proved the damaged zones to have different values of thermal parameters compared to the ones of structurally healthy zones of the data sheet.

3. A mathematical model of the heat exchange process and its realization by FEM model in COMSOL Multiphysics system were developed and thermal conductivity parameter of damaged and nondamaged teslin layer was identified from the results of experimental research. The simulation results of the process under identical heating and boundary conditions as during experimentation were found out to be in agreement with the experimental research results. This proves the model‘s validity.

4. Simulation of heat exchange process when the bottom surface of the data sheet was heated resulted in temperature differences on the top surface of the sheet at damaged and nondamaged zones sufficient for detecting with modern thermo vision cameras (0.5°C). Taking into account short duration of the process and reasonable heating temperatures ($T_0 \approx 27°C$) it can be concluded that analysis of temperature fields during heat transfer through the

sheet‘s thickness can be used as a method for structural integrity verification of the data sheet of a travel document.

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POLIKARBONATINIŲ ASMENS TAPATYBĖS DOKUMENTŲ STRUKTŪRINIO VIENTISUMO PATIKRA

R e z i u m ė

Vykstant globalizacijos procesams ir dėl to nuolat didėjant valstybių sienas kertančių asmenų skaičiui, ypač svarbu patikimai nustatyti asmenų dokumentų autentiškumą. Kai kelionės dokumentų patikrai yra skiriamos tik kelios minutės, kilus įtarimui, kad dokumentas gali būti sufalsifikuotas, svarbu turėti patikros būdų, paremtų techninėmis priemonėmis. Šis darbas skirtas kelionės dokumento duomenų lapo, kuris yra daugiasluoksnė polikarbonato-teslino struktūra, integralumo patikros metodo, paremto šilumos mainų proceso analize, tyrimams. Fizinių parametrų (nagrinėjamu atveju šiluminio laidumo) vertės mechaniškai pažeistose ir nepažeistose duomenų lapo zonose ištirtos eksperimentiškai. Sudarytas šilumos sklidimo duomenų lape matematinis modelis. Atliktas šilumos mainų proceso modeliavimas, kai duomenų lapo viena pusė tolygiai šildoma pastovios temperatūros šilumos šaltiniu. Gauti rezultatai patvirtina, kad priešingos dokumento lapo pusės paviršiaus temperatūrų skirtumas pažeistose ir nepažeistose zonose yra pakankamas, kad jį būtų galima nustatyti šiuolaikinėmis priemonėmis, o paties proceso trukmė bei šildymo temperatūrų diapazonas yra tinkami, kad siūlomas metodas galėtų būti praktiškai taikomas kelionės dokumentų patikrai.

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STRUCTURAL INTEGRITY VERIFICATION OF POLYCARBONATE TYPE PERSONAL IDENTITY DOCUMENTS

S u m m a r y

Under the effect of globalization and constantly increasing number of persons crossing state borders reliable authenticity assessment of personal identity documents is of crucial importance. As for inspection of the document only a few minutes are allocated, in the presence of signs of falsification or counterfeiting effective methods based on the application of technical devices are necessary. The research presents a method for structural integrity verification of a data sheet of multilayer structure polycarbonate – teslin by the analysis of heat exchange process in it. The change of physical parameters (thermal conductivity) at the mechanically damaged and nondamaged zones of the data sheet was experimentally researched. Mathematical model of heat exchange process through the thickness of the data sheet was built. Simulation results of the process indicate that difference of temperature on the sheet’s surface is sufficient for detection by modern devices, its duration and heating temperature are reasonable for practical implementation of the method in inspection of travel documents.

Keywords: multilayer, teslin, polycarbonate, heat exchange, personal identity document.

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