The object of this study is plastic cards for various purposes, which are a multilayer structure. The main factors affecting the wear of cards are environmental influences, storage and use conditions, and equipment for reading our personalized information. During the operation of plastic cards, the most common defects are peeling of the top protective layer and violation of the integrity of the card structure. An increase in the frequency of such operational defects may be caused at the production stage by the peculiarities of a die-cutting process.

The subject of the study is to determine the optimal technological parameters for laser processing of plastic cards in order to improve their quality characteristics, in particular, wear resistance. The process of card wear was simulated by exposure to chemical and mechanical factors. The study was conducted using a standard procedure. The new methodology includes a combination of classical tests: a combination of chemical and dynamic effects and the introduction of a washing test.

To solve the existing problem, it was proposed to improve the technological process by introducing laser edge processing of plastic cards after die-cutting. A set of experimental studies on resistance to transverse, longitudinal bending and twisting revealed that the wear resistance of cards after laser edge treatment increased by 12 % compared to untreated cards. It was established that for cards made of polyvinylidene chloride, processing with a CO_2 laser with a power of 25.5 W and a diameter of the laser beam of 1.5 mm is the most rational. It has been confirmed that this laser processing technique makes it possible to strengthen the chemical bonds between the layers of the body of a plastic card

Keywords: plastic card, wear of plastic card, multilayer structure, modes of laser processing, polyvinyl chloride

UDC 655.3.025:678.5/.8
DOI: 10.15587/1729-4061.2024.317448

DETERMINING THE INFLUENCE OF TECHNOLOGICAL PARAMETERS OF THE LASER PROCESSING OF PLASTIC CARDS EDGES ON IMPROVING THEIR WEAR RESISTANCE

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Received 17.09.2024
Received in revised form 12.11.2024
Accepted 27.11.2024
Published 20.12.2024

How to Cite: *Kyrychok, T., Nazarenko, O., Korotenko, O., Klymenko, T., Talimonova, N. (2024). Determining the influence of technological parameters of the laser processing of plastic cards edges on improving their wear resistance. Eastern-European Journal of Enterprise Technologies, 6 (1 (132)), 84–94. https://doi.org/10.15587/1729-4061.2024.317448*

1. Introduction

Plastic cards may have a large set of functions depending on the purposes of application and differ in the method of interaction with the reading device, the material and structure of the card body, the method of production and processing of the card, as well as the level of card protection [1].

The durability of plastic cards is ensured by the stability of their quality indicators over the entire life cycle. The main factors that affect the wear and tear of cards are the impact of the environment, conditions of storage and use, means of reading personalized information.

Increasing the wear resistance of plastic cards is ensured in various ways – both by the choice of materials and technological parameters. The main materials used for the production of cards are polyvinyl chloride (PVC), polycarbonate (PC), polyethylene glycol (PET), and special compositions [2].

To improve wear resistance, certain types of materials are used, which are combined with each other, enabling high adhesion during the manufacture of the card. Another means is the improvement of technological processes. As a plastic card wears out, due to the action of a number of factors, the loss of these properties may occur.

To increase the wear resistance of plastic cards, it is advisable to improve the technological process. In this respect, methods for card laser processing may prove promising, which requires additional study.

2. Literature review and problem statement

Work [2] analyzed the main factors that lead to plastic cards wear in the process of circulation. Based on this, a generalized classification of these factors was built, and a model of factors affecting the performance of plastic cards was constructed. In the work, all factors were divided according to the duration of exposure, the area of exposure, the source of exposure, presence of contact with a plastic card, and the type of energy applied [2]. The authors of [3] single out the following factors influencing the wear resistance of plastic cards: printing method; materials for production; the method of introducing a magnetic strip, microchip, scratch coating; methods for processing the surface of plastic materials; as well as embossing and lamination methods. Taking into account the studies reported in [2, 3], it is possible to conclude about the expediency of adjusting the technological regimes in order to increase the period of use of the card, which involves the change of equipment and the selection of other materials. However, in both works, the authors do not provide clear technological recommendations for changing the technological process in order to reduce the influence of the analyzed wear factors and to increase the wear resistance of plastic cards.

In [4], a more detailed analysis of the factors that affect the durability of plastic cards is carried out, and recommendations are given on the selection of the type of plastic cards and materials from the point of view of their durability. In particular, it has been determined that contactless cards are considered more wear-resistant (the maximum period of use reaches 10 years) than contact cards (the maximum period of use is 5 years), due to the absence of the need for physical contact with readers. Among dual-technology cards, dual-interface cards are considered more wear-resistant than hybrid cards, owing to the implementation of only one chip in the body instead of two, which provides both contact and contactless connections.

Paper [5] considers the security of using microcircuits on a flexible plastic base, which is questionable because of the possibility of reading the secret key using a microscope. The authors propose the use of private keys, as well as a new mechanism for programming a secret key that will be hidden. The authors identify the main advantage of using the designed electronic devices on plastic foil as increasing their safety, reducing the thickness of the material, and increasing the flexibility of the material. However, the authors do not mention anything about the wear resistance of these materials and the possibility of their use in daily circulation.

The author of paper [6] defines polycarbonate as the most wear-resistant material for the production of cards and identity documents. It provides a tougher card body material that is much more resistant to damage from heat, bending, and UV rays. However, the author does not mention that polycarbonate can have a tendency to become brittle [7], which in the case of card processing methods in circulation could cause them to wear out prematurely. At the same time, polycarbonate is an expensive material compared to other types of plastic, and therefore its use for some types of cards becomes impractical.

Various types of cards made of polyvinyl chloride (PVC) have become widespread. This type of plastic is one of the cheapest, but usually PVC cards have a life of 3–5 years. According to ISO 24789-1:2024, the main durability issues of PVC cards include: surface wear (scratches and erosion), delamination, physical stress (bending and twisting) on the card body, chemical damage, defects caused by certain personalization features.

Therefore, the authors of paper [4] recommend using multi-layer structures of the card body to increase their durability. In particular, it is recommended to cover the PVC case with PET film or other compositions with increased wear resistance. However, the authors of paper [4] focus on increasing the wear resistance of cards using similar methods from the point of view of better fixing of the chip and/or antenna in the case. However, the work does not note the possibility of additional layering of cards at the edges during the cutting and processing of cards in circulation.

The analysis of [8] and ISO 7810:2019 confirms that the multi-layering of plastic cards is a technologically necessary method for ensuring their functional, protective, and design features, but at the same time it is also one of the main reasons for reducing their wear resistance precisely because of the premature delamination of the card body structure. It is noted [8] that the delamination of the card is one of the most common types of defects both during the cutting of the card body in the process of their production and in the process of their circulation. In particular, it is known that due to the technological features of cutting cards, it is impossible to achieve a cut at an angle of 90° to the plane of the card [9]. Deviations are 1–4°, which can cause delamination when using the card. This applies to widely used PVC cards with different types of coating. However, the authors do not offer methods for avoiding the delamination defect.

An option to overcome the specified problem of reduced wear resistance due to delamination can be additional processing of the edge of plastic cards, in particular laser processing.

Laser treatment is widely used in various processes in the printing industry, in particular in the industry of production of various types of plastic cards. Areas of application of laser technologies during the production of plastic cards include engraving and marking of cards to protect against counterfeiting, laser personalization of cards, laser cutting of cards, laser processing of all kinds of shapes and structures in different layers of plastic cards. However, the technologies described in [10, 11] refer to polycarbonate plastic cards. Research on the use of laser processing of the edge of the card with other types of plastic, in particular with multilayer PVC cards, is lacking.

Therefore, our review of the related literature demonstrated the incompleteness of theoretical and practical work on improving the technological processes of manufacturing plastic cards in order to increase their durability, in particular, the use of laser technologies for this purpose. Thus, it can be stated that conducting research on the improvement of technological processes of manufacturing plastic PVC cards using laser edge processing is expedient and relevant to improve their wear resistance.

3. The aim and objectives of the study

The purpose of our work is to determine the effect of laser edge processing on the properties of a plastic card and to improve the technological process. This will ensure a reduction in the level of defects in the delamination of the card structure both during their production and in the process of circulation.

To achieve the goal, the following tasks were set:

– to conduct a microscopic examination of the edge of the cards for their quality characteristics, in particular wear resistance after various modes of laser processing;

– to perform a visual assessment of the quality, in particular of wear resistance, of plastic cards after being exposed to laser processing;

– to devise technological recommendations for laser processing of the edges of PVC plastic cards.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the technological process of manufacturing plastic cards with laser processing of the edge to increase their wear resistance.

It was hypothesized that by strengthening the polymer bonds between the layers of a PVC plastic card, its resistance to wear and tear during use would increase.

It was assumed that laser treatment of the edge of the plastic card could help strengthen the bonds between the layers of the plastic card, provided that the mode of laser treatment of the edge of the cards is selected accordingly. This would improve the resistance of cards to delamination under the influence of interaction with the user, environment, and equipment.

Adopted simplifications are changes in the parameters of the laser beam. Specifically, its diameter, intensity, and direction of movement relative to the experimental sample.

4. 2. Materials for research

According to ISO 7810:2019, a plastic card is a multi-layer structure made of different types of plastic, rectangular in shape with rounded corners, measuring 85.60×53.98 mm. A standard plastic card has rounded corners with a radius of 2.88–3.48 mm and a thickness of 0.76 mm. The physical characteristics of plastic cards are also standardized according to ISO 7810:2019. The main technical characteristics of the applied material [12] for the manufacture of the studied plastic cards are given in Table 1.

The characteristics of the material have a significant impact on the properties of the plastic card during its further use.

4. 3. Structure of the studied samples

1020 plastic cards were produced for experimental research. Each experimental sample of a plastic card was made of polyvinyl chloride (PVC) manufactured by the Klöckner company [13].

Samples of two types were produced:

– sample type 1 is a contactless plastic card containing two layers of PVC of 0.1 mm and two layers of PVC with an adhesive layer of 0.08 mm, in the middle a layer with Em-Marine chips – 0.4 mm;

– sample type 2 – a contact plastic card with a magnetic stripe on the reverse side, containing two layers of PVC plastic with a thickness of 0.3 mm and two layers of PVC plastic with an applied adhesive layer with a thickness of 0.08 mm.

The structure of the tested samples of different types of plastic cards is shown in Fig. 1.

The multi-layered nature of the plastic card has a significant impact on the plastic card wear during its circulation. The formation of strong bonds between layers of materials makes it possible to improve the resistance of cards to delamination.

Table 1

Specifications of the material for making cards

Name	Technical characteristics of white and transparent PVC
Appointment	Offset/screen printing using UV inks
Surface property	Matte on both sides
Surface treatment	Without coating
Thickness, mm	0.3±0.015
Surface tension on the side intended for printing, dyn/cm	40–42
Surface tension on the back of the sheet, dyn/cm	34–36
Evenness of paint application and absorption	Absence of unprinted white spots after paint application
Maximum shrinkage at 140 °C/10 min, %: MD – longitudinal, CD – transverse	MD≥–4.5; CD≤+2.0
Vicat point B50 (5 kg), °C	74±2
Surface roughness on the side intended for printing Ra, µm	0.5–1.8
Tensile strength, N/mm^2	≥46
Density, g/cm^3	1.25–1.45
Additional requirements	– sheet corners must be equal to 90°
	– absence of uneven cutting of sheet edges

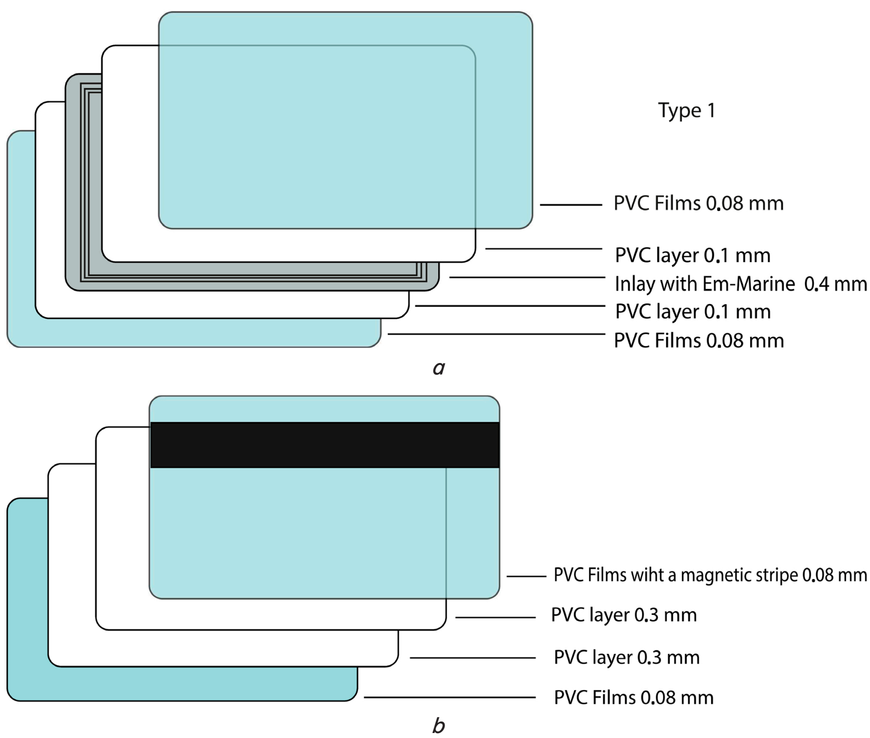

Fig. 1. Structure of the examined samples of plastic cards of different types: *a* – contactless plastic card with an Em-Marine chip (type 1); *b* – contact plastic card with a magnetic strip (type 2)

4. 4. Technological process of manufacturing plastic cards

Cards were produced using an offset printing method on a Heidelberg CD-74 offset printing machine [14] using UV fixing inks for printing on plastic produced by Huber [15]. The products were printed with their reverse side, the front and back side of the card were printed at once. After printing, the package was assembled for card lamination. Two sheets of transparent plastic with an applied adhesive layer and two printed sheets of PVC were used for assembly. After that, the collected packages were laminated on a laminating machine LAUFFER LCL 40-80-4 [16]. Cards were cut using LOUDA DC-510 equipment [17].

After cutting, the samples were tested for resistance of the top layer to delamination using a device for testing adhesion of the adhesive layer [18] according to ISO 10373-1:2020. The sample was made from 2 cards from each laminated pack of sheets.

4. 5. Algorithm for investigating plastic cards for wear resistance

From the manufactured samples of plastic cards (1020 pcs.), 2 samples of cards were formed according to their type. From each sample, 20 samples were selected, which formed control groups within each sample. Control groups were not subjected to any additional treatment. The quality indicators of control groups of samples served as reference values for further studies. In particular, a microscopic study of the edge of the cards from the control groups was carried out.

The remaining cards from each sample were divided into 20 groups of 16 samples each. The cards of each group were subjected to laser processing with different parameter settings. Thus, 16 technological modes of laser processing were applied within each group.

The next stage was conducting research on wear resistance of the cards. To this end, 4 separate samples of cards were formed for carrying out different types of tests: dynamic resistance, resistance to alcohol, resistance to vinegar, according to ISO 10373-1:2020, washing test. Each card sample consisted of 15 groups of cards (5 groups of each card type) that were lasered and 15 samples taken from a control group of the corresponding card type that were not lasered.

After testing for wear resistance, all cards were visually evaluated according to the devised methodology, and microscopic studies of the edge of the cards were carried out. At this stage, it was important to investigate the influence of technological parameters of laser processing on the preservation of the wear-resistant characteristics of various types of plastic cards.

Before and after the laser treatment, the quality of the treatment was measured using a Sigeta Biogenic Lite 40x optical microscope [19] with the possibility of photo-recording the results. The research methodology involved measuring the thickness of the edge in the processing area, visually assessing the structure of the layers before and after laser processing, determining the change in the color characteristics of the edge of the examined card samples.

The research results were subjected to statistical treatment and analysis. Based on this, technological recommendations have been devised for selecting the technological parameters for laser processing of various types of plastic cards in order to ensure high quality indicators, in particular wear resistance.

4. 6. Methodology for laser processing of the edge of plastic cards

After cutting, laser processing of the edges of plastic card samples was carried out in groups of 16 cards. For processing, a block of 16 cards was fixed with metal clips. Laser processing was carried out using a BODOR BCL-1610x laser device [20]. Parameters of the technological process of laser processing are as follows: CO_2 laser with a laser wavelength of 10.6 µm, the pulse frequency is adjustable, in the range of 20–30 kHz.

To control the technological process of laser processing of the edge of a plastic card, the RDWorks V8 software supplied with the laser equipment was used [20]. Fig. 2 shows the operational scheme of the laser device. The operating parameters of the laser, the diameter of the radiation beam, the conditions of concentration of its energy on the card blank, the optical and physical properties of the processed material of the blank and its dimensions were pre-set (Table 2).

An experiment was carried out with different settings of laser processing parameters (Table 2). The constant factors in the study were the type of laser (CO_2) and its power (25.5 W), the material of the card (PVC), and its density (1.45 g/cm^3). The variables of the experiment were the thickness of the block of 16 cards (due to the different thickness of the cards), which was fixed using metal clamps, the diameter of the laser beam (1–3 mm), and the positioning of the laser relative to the samples (transverse and longitudinal).

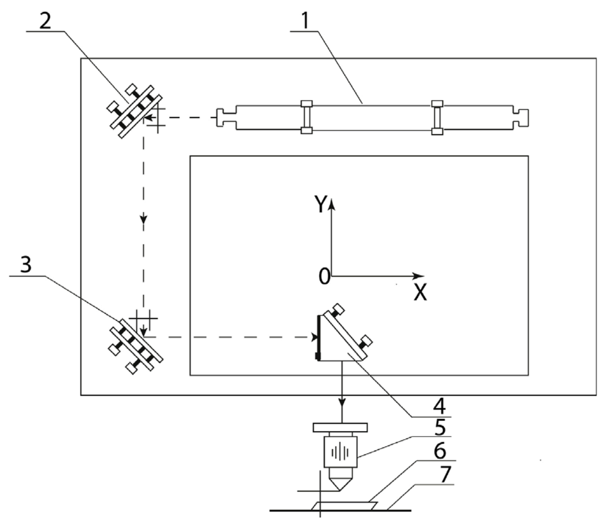

Fig. 2. Operational scheme of the laser device: 1 – laser tube; 2 – the first reflecting mirror; 3 – the second reflecting mirror; 4 – the third reflecting mirror; 5 – focal lens; 6 – plastic card; 7 – desktop

Table 2

Setting modes for laser processing of plastic cards

Mode No.	Laser beam diameter	Laser positioning relative to samples	Mode No.	Laser beam diameter	Laser positioning relative to samples
1	3	transverse	9	1.25	transverse
2	3	longitudinal	10	1.25	longitudinal
3	2.5	transverse	11	1	transverse
4	2.5	longitudinal	12	1	longitudinal
5	2	transverse	13	1	transverse
6	2	longitudinal	14	1	longitudinal
7	1.5	transverse	15	1.25	transverse
8	1.5	longitudinal	16	1.25	longitudinal

A different position of the laser relative to the treated surface and a change in the diameter of the radiation made it possible to expand the selection of samples for research. It was these setting parameters that had the greatest impact on the quality of the surface treatment.

4. 7. Methodology for determining the effect of laser processing on wear resistance of plastic cards

Test samples without treatment and with laser treatment were divided into groups according to ISO 10373-1:2020:

1. Chemically exposed:

1. 1) treated with an alcoholic solution of CH_3CH_2OH;

1. 2) treated with a solution of acetic acid CH_3COOH;

1. 3) subjected to dynamic influence on bending (transverse, longitudinal, and torsion);

2. Subjected to chemical influence and dynamic influence on bending (transverse, longitudinal, and torsion):

2. 1) treated with an alcohol solution and subjected to dynamic bending (transverse, longitudinal, and torsion);

2. 2) treated with a solution of acetic acid CH_3COOH and subjected to dynamic bending (transverse, longitudinal, and torsion).

3. Subjected to dynamic and thermal effects in the environment of a washing machine for 90 minutes at a temperature of 60 °C with a drum rotation frequency of 1000 rpm in clean water without the addition of chemicals.

The wear resistance of the cards was tested in accordance with ISO 10373-1:2020. The card samples were dynamically subjected to bending (transverse, longitudinal, and torsional). Testing was carried out under normal climatic conditions at a temperature of 23 °C and a humidity of 40 %.

The cards were placed in the clamp of the ICTR (ID card tester) [21] bending and twisting machine, and each of the samples was bent in three positions for 1000 cycles on each side of the card. A sinusoidal effect with a frequency of 0.5 Hz was applied to the card.

The methodologies of ISO 10373-1:2020 were supplemented by a combination of different types of research and the introduction of a washing test: the resistance of the cards to the influence of chemical reagents, in particular, to the action of alcohol solution and acetic acid solution, and also the resistance of the cards to dynamic influence was investigated.

4. 8. Methodology for visual assessment of the quality of plastic cards

The visual evaluation of the samples was carried out according to the methodology that we devised, based on the modification of scoring methods and pairwise comparisons of ISO 5495:2016 and additionally developed methods for investigating other polygraphic products [20]. The modification of the methods involved their adaptation with respect to the quality indicators of plastic cards, and providing an assessment to the sample samples when comparing them, which allowed us to improve the objectivity of visual assessment.

The assessment was carried out by four independent groups of experts, each of which consisted of two people – an experimenter and a respondent, who jointly formed an agreed assessment of each sample of a plastic card. The obtained evaluations of each sample were averaged relative to all the samples involved in the experiment, then within the expert groups, and also within the groups in the samples.

Visual assessment was carried out twice during the experiment. The first evaluation was carried out with samples to which only laser treatment was applied. The second evaluation was carried out with samples (both laser-treated and untreated) that were subjected to various wear resistance tests.

During the first evaluation, a change in the visual properties of the card, in particular a change in the color of the edge of the card, was determined as an indicator of the quality of the plastic cards. During the second evaluation, another indicator of the quality of plastic cards was added – the presence of card delamination.

The evaluation algorithm is as follows:

1. The experimenter completes two samples from the sample of plastic cards in different combinations and offers the respondent to evaluate their quality according to the specified indicator. At the same time, each sample must be compared with five randomly selected samples from the sample.

2. The respondent examines the samples in detail each time, comparing them with each other, and assigns them grades. The sample that, in the opinion of the respondent, is determined to be worse than the other in terms of the level of expression of the specified indicator, receives a score of 0, the best sample – a score of 1. In the case of uncertainty by the expert of the best (or worst) sample, both samples are assigned the same level of assessment: score 1 in the case of good quality of both plastic cards in the expert's opinion, score 0 – in the case of poor quality of both plastic cards.

3. Recording the evaluations of the respondents for each sample a_{ij}^{mlk} in the evaluation matrices $A^{mlk}=[a_{ij}^{mlk}]$, where $m=\overline{1,5}$ is the number of the pair when compared, $l=\overline{1,4}$ is the number of the group of experts, $k=\overline{1,2}$ is the number of the group in the sample, $i=\overline{0,16}$ is the serial number of the sample in the group, $j=\overline{1,2}$ is the number of the sample.

At the same time, during the first visual evaluation of samples, samples are formed only by the type of plastic cards (i.e., 2 samples). Each sample consists of 20 groups of sample cards. Each group consists of 16 samples of cards, each processed under different technological modes. During the repeated visual evaluation of the laser-treated samples, which were also subjected to the wear resistance test, each sample of cards formed by the type of plastic cards was further divided into groups to carry out different wear resistance tests. Thus, five groups of cards were selected from each sample of cards, which have been subjected to various types of research on wear resistance (resistance to bending and twisting, resistance to the influence of 9 % acetic acid, resistance to the influence of alcohol, washing test).

4. Constructing a matrix of the average evaluation of the samples within the samples for each expert group:

$$A^{lk}=\left[a_{ij}^{lk}\right],$$

where

$$a_{ij}^{lk}=\frac{1}{m}\sum\nolimits_m a_{ij}^{mlk}. \qquad (1)$$

5. Constructing a matrix of the average evaluation of the samples within the samples by all expert groups:

$$A^{k}=\left[a_{ij}^{k}\right],$$

where

$$a_{ij}^{k}=\frac{1}{l}\sum\nolimits_m a_{ij}^{lk}. \qquad (2)$$

6. Constructing a matrix of average evaluation of samples by all groups in samples by all expert groups:

$$A = a_{ij},$$

where

$$a_{ij} = \frac{1}{k}\sum_{i} a_{ij}^{k}. \qquad (3)$$

7. Conversion of sample grades relative to the 100 percent grading scale:

$$A = \left[100 \cdot a_{ij}\right]. \qquad (4)$$

As a result of the visual evaluation, each sample of the corresponding sample receives a certain number of points. On the basis of this assessment, the quality level of the plastic card manufactured and processed under different technological regimes is established.

5. Results of investigating the effect of laser processing of the edge of a plastic card on its wear resistance

5. 1. Results of a microscopic study on the influence of the technological process of laser processing of the edge of the card on its wear resistance

The results of a microscopic examination of the edges of cards using different modes of laser processing are shown in Fig. 3.

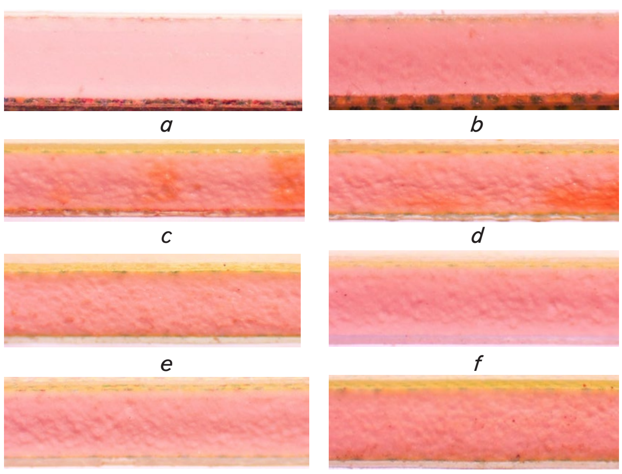

Fig. 3. Photomicrographs of the edge of the card: *a* – type 1 before laser processing; *b* – type 2 before laser processing; *c* – type 1 with beam D=1 mm, *d* – type 1 with beam D=1.25 mm, *e* – type 1 with beam D=1.5 mm, *f* – type 1 with beam D=2 mm, *g* – type 1 with beam D=2.5 mm, *h* – type 1 with beam D=3 mm

It was found that, according to the visual evaluation of the microphotographs of the samples, a change in the color of the edge of the laser-treated card with a beam diameter of 1 mm is observed. This is because the card material overheats with this laser setting. Under laser processing modes with a beam diameter greater than 1.5 mm, no visual changes were observed at the edge of the card.

The results of our research revealed that the cards without laser processing underwent minor changes under the influence of dynamic bending loads (transverse, longitudinal, and twisting). The greatest damage was found on untreated cards after exposure to CH_3CH_2OH alcohol solution and dynamic loading. Fig. 4 shows microphotographs of the edge of the studied samples without laser treatment and with laser treatment with a laser diameter of 1.5 mm (mode 7), exposed to alcohol CH_3CH_2OH and dynamic loading.

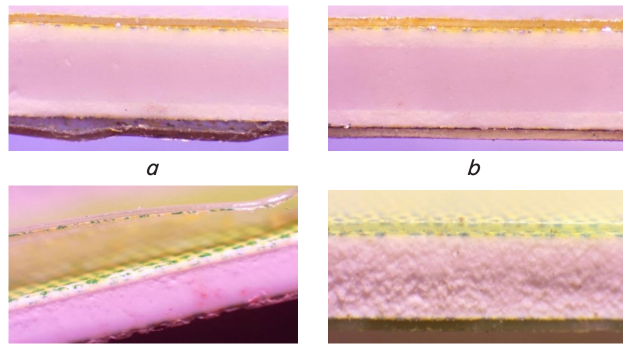

Fig. 4. Micrographs of the edge of the studied samples without laser processing and with laser processing after exposure to alcohol solution and dynamic load: *a* – sample type 1 without laser processing; *b* – type 1 sample with laser processing; *c* – type 2 sample without laser treatment; *d* – type 2 sample with laser treatment

On non-laser-treated cards that were exposed to alcohol solution and dynamic loading, peeling of the top coating on the edges was observed. Cards whose edges were treated with a laser with a beam diameter of 1 mm showed minor damage and peeling; processing with a laser diameter of 1.5 mm – no peeling was detected.

Cards that were treated with a vinegar solution and then dynamically exposed also showed no signs of damage.

5. 2. Results of visual assessment of the quality of plastic cards after exposure to laser processing

Fig. 5 shows the results of an averaged visual assessment of the quality of plastic cards that were subjected to laser processing with 16 different settings. During this evaluation, the quality indicator of the plastic cards was determined by the change in the color of the edge of the card. The experts determined the non-laser-treated samples as reference in terms of visual characteristics, therefore, such samples of plastic cards of both groups received a rating of 1.

From Fig. 5, one can see that among the processed samples, the best score for both types of cards was achieved using laser processing mode 6. Cards of both types processed using laser processing modes 11, 12, 13, and 14 received the lowest ratings from experts. In most cases, it was determined that the first type of cards showed better visual evaluation results than the second type of plastic cards.

The following visual evaluation was carried out with untreated and treated cards with 16 different laser modes, which were additionally subjected to various types of wear resistance tests. During these evaluations, the presence of card delamination was determined as a quality indicator of plastic cards.

Fig. 6 shows the results of a visual assessment of the quality of cards after exposure to dynamic load according to our methodology. One can see from the diagram (Fig. 6) that after exposure to dynamic load the best averaged visual scores from the four groups of experts were obtained by the 8-mode laser-treated type 1 card samples and the 4-mode laser-treated type 2 card samples. The worst quality was demonstrated by the samples of both types treated with a laser under mode 13. A clear trend of the influence of dynamic loads on different types of cards was not observed. One can see that, by visual assessment, samples of cards processed under 2, 4, 7, 8, 9 modes have better quality than untreated samples.

Fig. 7 shows the results of a visual assessment of the quality of the cards after exposure to the CH_3CH_2OH alcohol solution and dynamic loading according to our methodology, where it was determined that the 7th mode of laser processing has the best effect on the quality of both types of cards. Type 1 plastic cards lasered under mode 4 also scored highest, but type 2 cards with the same treatment scored average. The worst scores were given to samples of both types of cards that were not laser-treated. In particular, on cards of type 1, after exposure to alcohol, peeling of the upper protective layer along the perimeter of the card is observed, there are slight distortions of the image in the places where the protective layer is peeled off. Plastic cards of type 2 have significant distortions of the plot from the face and back of the card along the edge in places where the protective film peels off, and with the application of minor efforts, the edges peel off.

Fig. 8 shows the results of a visual assessment of the quality of the cards after dynamic and temperature exposure in the environment of the washing machine for 90 minutes at a temperature of 60 °C with a drum rotation frequency of 1000 rpm in clean water without the addition of chemicals.

From Fig. 8, one can see that type 2 cards had better quality after the dynamic and temperature effects of the washing test both under all modes of laser processing and in the absence of processing. This can be explained by the better flexibility of type 2 cards due to their smaller thickness than type 1 cards. The best grades were obtained by cards that were processed using the 8th mode of laser processing. The worst scores were received by cards without processing and processed with 6 and 16 laser processing modes, in particular type 1 cards.

According to the results of a visual assessment of the quality of cards after exposure to a solution of acetic acid CH_3COOH according to our methodology, no visual changes were found on all cards, which proves that PVC plastic cards are inert to the influence of acidic environments.

The diagram in Fig. 9 shows the positive effect of laser processing of both types of cards on the overall quality, in particular on wear resistance. It was also determined that type 1 cards treated with a laser under 8 mode, type 2 cards – treated with a laser under 7 mode received the highest visual evaluation. The lowest scores among the laser-treated cards were obtained by samples of both types of cards with laser treatment modes 11, 12, 13, and 14. However, even these scores are higher than scores for cards that have not been laser edged.

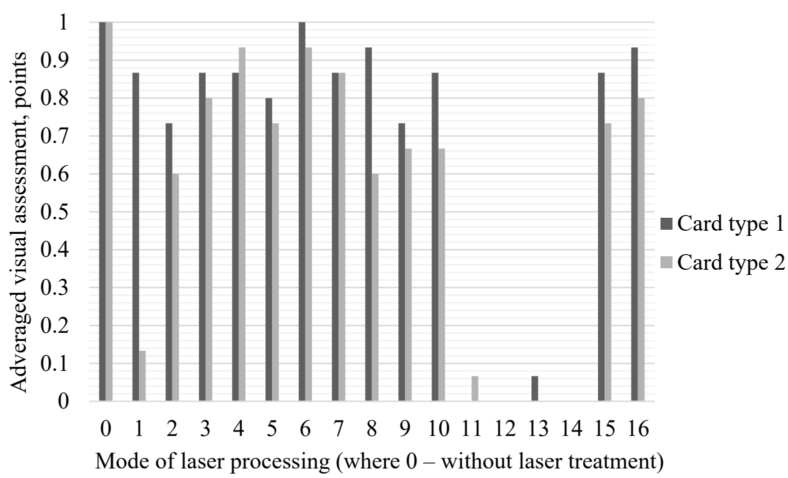

Fig. 5. Averaged visual assessment of the quality of cards subjected to different modes of laser processing (without dynamic and chemical effects)

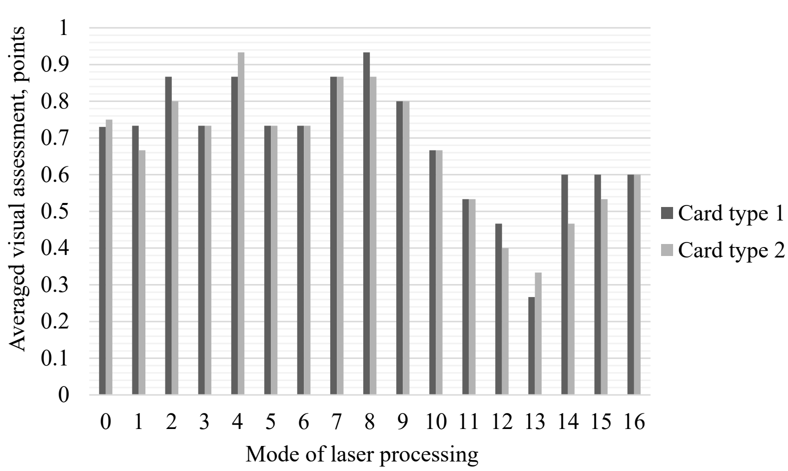

Fig. 6. Averaged visual assessment of card quality after exposure to dynamic load

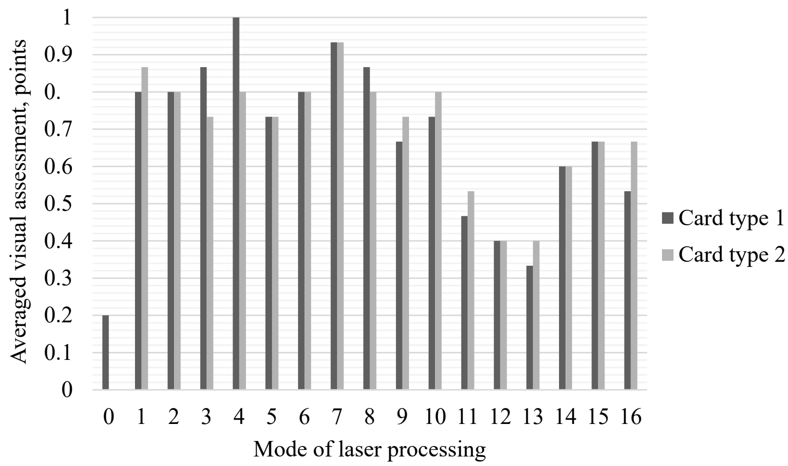

Fig. 7. Averaged visual assessment of the quality of cards after exposure to alcohol solution CH_3CH_2OH and dynamic load

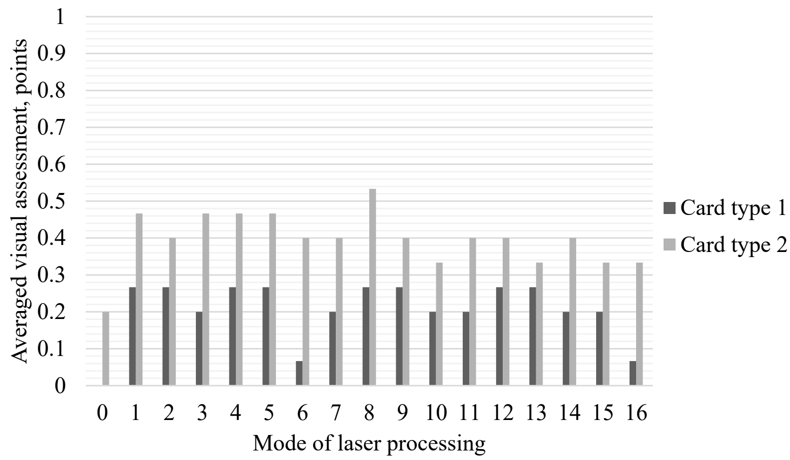

Fig. 8. Averaged visual assessment of the quality of the cards after the washing test

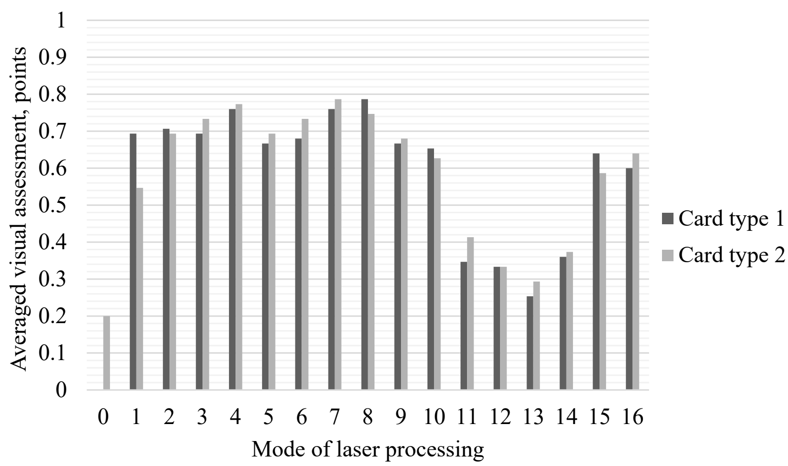

Fig. 9. Averaged visual assessment of card quality after all types of wear resistance tests

Thus, a general assessment of the quality of card samples of both types processed by laser under 16 different modes and subjected to various types of tests has been derived.

5. 3. Technological recommendations for processing the edge of PVC plastic cards with a laser

Fig. 10 illustrates dependence of the generalized visual assessment of the quality of cards of both types on the diameter of the laser beam during their processing. As can be seen from Fig. 10, card samples of both types lasered with a laser beam diameter of 1 mm received the worst ratings, samples lasered with a laser beam diameter of 1.5 to 2.5 mm received the best ratings.

Thus, according to the results of our tests, to increase the wear resistance of plastic PVC cards, it is advisable to introduce laser edge processing into the technological process of card production.

In this case, one should use a laser with a laser beam diameter of 1.5 to 2.5 mm and longitudinal positioning of the laser relative to the samples.

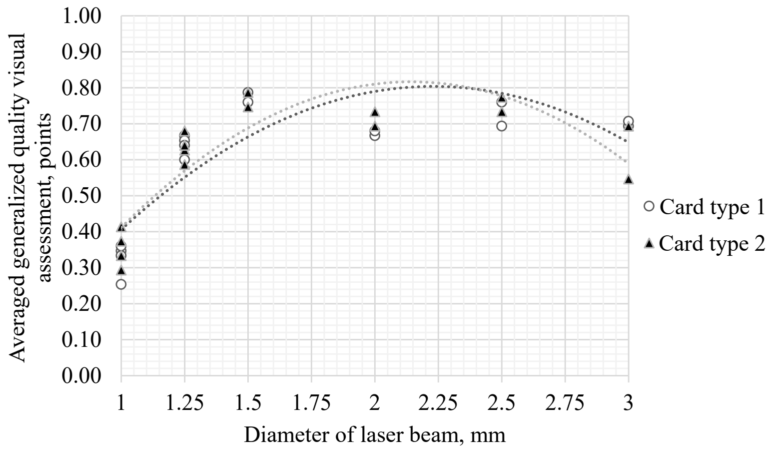

Fig. 10. Dependence of the generalized visual assessment of the quality of laser-treated cards of both types on the size of the diameter of the laser beam

6. Discussion of results of investigating the effect of laser processing of the edge of a plastic card on its wear resistance

The results of our microscopic study have made it possible to reveal that the laser treatment of the edge of the cards increases wear resistance.

It was determined that during laser processing with a beam diameter of 1 mm, a change in the color of the edge is observed (Fig. 3), which can be explained by the fact that with such settings and focusing of the laser, overheating of the card material occurs. Under laser processing modes with a beam diameter greater than 1.5 mm, visual color changes on the edge of the card are not observed (Fig. 3, 5).

The results of a visual assessment of the quality of the cards after a series of tests revealed the following:

1. After exposure to a dynamic load on the cards, slight delamination of the card was detected under laser processing modes with a beam diameter of 1 mm (Fig. 6). The delamination of samples with this type of pretreatment exceeds the delamination at the edge of untreated cards. The obtained results show that processing modes No. 11–14 (Table 2) are inappropriate to use for this type of cards. Samples of cards processed under modes 2, 4, 7–9 have better quality than untreated samples, so they are appropriate for inclusion in the technological process.

2. After exposure to the CH_3CH_2OH alcohol solution and dynamic load on the cards, peeling of the upper protective layer along the entire perimeter of the cards that were not subjected to prior laser processing was detected (Fig. 8); slight local delamination of the card under laser processing modes with a beam diameter of 1 mm. Card samples processed under mode 7 have the best quality and no peeling.

Our results are based on the fact that the action of the laser beam under a correctly selected mode contributes to the sintering of the layers of the card and provides better resistance to mechanical impact and the impact of chemical reagents.

Comparing our findings with previous studies, the following conclusions can be drawn:

1. In contrast to works [2, 3], in which authors analyzed the factors of wear of plastic cards, we have proposed recommendations for introducing laser processing of the edge of cards into the technological process in order to reduce the impact of factors of wear on the cards.

2. In contrast to the works in which the authors recommend changing the card type [4] and its material [5] to increase the durability of cards, we provide recommendations for improving the wear resistance of the already developed design and commonly used card materials, the production of which is established at enterprises. This will avoid the complete replacement of manufacturing technologies and materials due to the introduction of one additional technological operation and the addition of existing equipment.

3. In contrast to works [7], which investigated the reasons for the decrease in the wear resistance of cards and found that the main reason for them is multi-layering, but did not propose methods to avoid the defect of delamination, we have suggested laser processing of the edge of the card where the occurrence of delamination is most likely.

4. Works [8, 9] considered only cards made of polycarbonate. They describe in detail the possibility of using laser technologies for engraving, marking, personalizing cards, laser cutting and processing all kinds of shapes and structures in different layers of cards, but there have been no studies on the use of laser technologies with other types of plastic, in particular with multilayer PVC cards and studies of laser card edge processing.

Thus, based on the results of tests to improve the quality of PVC plastic cards, in particular to increase their durability, laser edge processing should be introduced into the card manufacturing process.

The research is limited to the use of only one type of material in the testing process – polyvinyl chloride. It is possible to expand the line of materials. The production of plastic cards is recommended to be complemented with the testing of polyethylene glycol and polystyrene cards.

Analysis of the color change of the edge of the plastic card after laser processing is limited to the visual assessment of experts. For a more objective result, it is necessary to implement an instrumental measurement with the determination of the color deviation indicator ΔE from the reference sample.

The main drawback of this study is the destruction of the body of the card during the testing process. Most of the samples become unsuitable for further use at the stage of selection of laser processing modes. The very process of determining the stability of bonds between layers of plastic also requires the destruction of the sample.

The use of this technology in the production process requires additional investments and an increase in the production time of the plastic card, which in the future will affect its cost price. However, this disadvantage is compensated for by increasing the resistance of the card to wear and tear during operation.

Test methodologies that have been used could be improved by adding new test methods. In further studies, it is recommended to pay attention to the influence of radiation (electromagnetic, UV radiation) on the wear of a body of the plastic card.

7. Conclusions

1. The results of our microscopic studies demonstrate a positive effect of laser processing of the edge of a plastic card on wear resistance. Strengthening the polymer bonds by laser welding improves the card's resistance to delamination. According to the results of the microscopic examination of the edge, it can be concluded that the most optimal diameter of the laser beam during processing is 1.5–2.5 mm. On the examined cards, which were subjected to chemical exposure to acetic acid and alcohol solutions and additionally to dynamic exposure (transverse and longitudinal bending and twisting), the best results were obtained for cards treated with a laser beam diameter of 1.5 mm. On these cards, there is no delamination of the top layer of the card, the integrity of the card structure is observed, there is no delamination of the card body.

2. Based on the results of visual assessment of the quality of plastic cards after exposure to laser treatment, it can be concluded that the results of the expert assessment indicate an improvement in the wear resistance of cards with laser treatment compared to untreated cards. The best are the modes of processing cards of type 1 under mode 8 (diameter 1.5 mm, longitudinal positioning of the sample) and cards of type 2 under mode 7 (diameter 1.5 mm, transverse positioning of the sample).

The standard methodologies regulated by ISO 10373-1:2020 have been improved by supplementing them with other methods for studying the wear of plastic cards. In particular, a study was conducted with a simultaneous combination of chemical and dynamic exposure; the washing test and visual evaluation were added to assessment. That made it possible to obtain results that are closer to the conditions of using cards in circulation.

3. Based on our results, recommendations were compiled regarding the processing of cards made of PVC with the help of a laser. The use of a processing mode with a laser diameter of 1.5–2.5 mm has been proposed. This operation needs to be integrated into the technological process of manufacturing cards; however, it can be implemented without introducing a separate operation. An alternative option is to add laser processing by a separate section on the equipment for applying personalized information. The operation is separate (additional) but can be implemented by upgrading existing equipment.

The additional operation of laser processing of the edge of the plastic card made it possible to improve the wear resistance of plastic cards by 12 % compared to untreated cards.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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