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THE IMPROVED APPROACH TO THE DEVELOPMENT OF PARAMETERS FOR THE INNER SHAPE OF MILITARY BOOTS

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THE IMPROVED APPROACH TO THE DEVELOPMENT OF PARAMETERS FOR THE INNER SHAPE OF MILITARY BOOTS

ABSTRACT. In the work, anthropometric studies of the feet were performed by means of 3D scanning. The results of scanning have been used for two main purposes. Firstly, the features and morphological structure of the feet of young men aged 20-30 were studied, who are the representatives of the Ukrainian population that are subject to mobilization into the ranks of the Armed Forces. Apart from this, the quantitative distribution of the main morphological features of the feet of the sample population was analyzed. During measurements, it was noticed that a large number of men had hypertrophy of the heads of the 1st and 5th metatarsal bones. In order to rationalize the range of lasts with different sizes and fullness, while trying to fully satisfy the requirements of compliance with the anthropometric parameters of the feet of consumers, the parameters of the feet with the hypertrophy of the heads of the 1st and 5th metatarsal bones must be taken into account in the lasts with increased width. Furthermore, the results of scanning constitute the basis for calculating and developing basic parameters of lasts. For this, the work suggested the method of designing a last shape based on such types of input data as a digital foot model, dimensional foot parameters, and a foot print obtained as a result of mass 3D scanning of the feet.

KEY WORDS: footwear last, shoe last design, footwear inner shape, military boots, 3D scanning, foot parameters

O ABORDARE MAI BUNĂ PRIVIND DEZVOLTAREA PARAMETRILOR PENTRU FORMA INTERIOARĂ A BOCANCILOR PENTRU ARMATĂ

REZUMAT. În lucrare s-au efectuat studii antropometrice ale piciorului prin scanare 3D. Rezultatele scanării au fost utilizate în două scopuri principale. În primul rând, s-au studiat caracteristicile și structura morfologică a picioarelor tinerilor cu vârste cuprinse între 20-30 de ani, care sunt reprezentanții populației ucrainene supuse mobilizării în rândurile Forțelor Armate. În afară de aceasta, s-a analizat distribuția cantitativă a principalelor caracteristici morfologice ale picioarelor populației eșantion. În timpul măsurătorilor, s-a observat că un număr mare de bărbați prezentau hipertrofie a capetelor metatarsiene 1 și 5. Pentru a raționaliza gama de calapoade cu diferite dimensiuni și volume, încercându-se în același timp să se îndeplinească cerințele de conformitate cu parametrii antropometrici ai picioarelor consumatorilor, trebuie să se țină seama de parametrii picioarelor cu hipertrofia capetelor metatarsiene 1 și 5 la calapoadele cu lățime mare. În plus, rezultatele scanării constituie fundamentul pentru calcularea și dezvoltarea parametrilor de bază ai calapodului. Pentru aceasta, în lucrare a fost sugerată metoda de proiectare a unui calapod pe baza unor date de intrare precum un model digital al piciorului, parametrii dimensionali ai piciorului și o amprentă a piciorului obținută ca urmare a scanării 3D în masă a picioarelor.

CUVINTE CHEIE: calapod, designul calapodului, forma interioară a încălțămintei, bocanci pentru armată, scanare 3D, parametrii piciorului

UNE MEILLEURE APPROCHE POUR LE DÉVELOPPEMENT DES PARAMÈTRES POUR LA FORME INTÉRIEURE DES BOTTES MILITAIRES

RÉSUMÉ. Dans le travail, des études anthropométriques des pieds ont été réalisées au moyen de la numérisation 3D. Les résultats de l'analyse ont été utilisés à deux fins principales. Premièrement, ont été étudiées les caractéristiques et la structure morphologique des pieds de jeunes hommes âgés de 20 à 30 ans, qui sont les représentants de la population ukrainienne soumise à la mobilisation dans les rangs des Forces Armées. En dehors de cela, la distribution quantitative des principales caractéristiques morphologiques des pieds de la population de l'échantillon a été analysée. Lors des mesures, il a été remarqué qu'un grand nombre d'hommes présentaient une hypertrophie des têtes des 1er et 5e métatarsiens. Afin de rationaliser la gamme de formes chaussures avec différentes tailles et plénitude, tout en essayant de satisfaire pleinement aux exigences de respect des paramètres anthropométriques des pieds des consommateurs, il faut prendre en compte les paramètres des pieds avec l'hypertrophie des têtes des 1er et 5e métatarsiens dans les formes avec une largeur augmentée. De plus, les résultats de la numérisation constituent la fondation pour le calcul et le développement des paramètres de base des formes. Pour cela, dans le travail, on a suggéré la méthode de conception d'une forme chaussures basée sur des types de données d'entrée tels qu'un modèle de pied numérique, des paramètres dimensionnels du pied et une empreinte de pied obtenue à la suite d'un balayage 3D des pieds en masse.

MOTS CLÉS : forme de la chaussure, conception de la forme de la chaussure, forme intérieure de la chaussure, bottes militaires, numérisation 3D, paramètres du pied

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INTRODUCTION

Despite the fact that scientific progress has reached all the spheres of life, making it more comfortable and convenient, we still often wear uncomfortable shoes. Today, in manufacturing footwear of mass production, all the features of three-dimensional shape of the foot of a potential consumer are rarely taken into account. Instead, in the best-case scenario, 2 or 3 measurements of the typical average foot of certain population are relied upon. This results in the production of shoes that consumers need to wear in and adapt to the shapes of their feet. This variant is unacceptable for children, the elderly, as well as consumers with feet deformities. In addition, it is inappropriate for specialized shoes that are to be actively worn during a long time and those that are supposed to be used in harsh conditions. The requirements for sports and military footwear are linked to the increased comfort as a factor that influences achieving high results or performing professional tasks.

In the context of current military aggression against Ukraine and with the need to mobilize men into the ranks of the Armed Forces of Ukraine, it is particularly important to properly provide military personnel with the necessary equipment and ammunition. Comfortable footwear is an essential and indispensable component of the apparel of fighters and other members of the security agencies of Ukraine. With that, the convenience of boots is one of the most important factors in the quality of uniforms, which contributes to the overall feeling of comfort, reduces fatigue, and increases performance during the entire period of wearing them [1]. One of the major conditions of making footwear comfortable is the conformity of the shoe last on which a shoe is made to the shape and size of consumer's foot. Analyzing the quality of domestically produced military footwear, consumers highlight that it is not comfortable enough. The fact is that domestically produced military boots are manufactured either on the outdated lasts of the Soviet model of the 70's, or on random lasts, the shape of which is not substantiated from the anthropomorphological point of view.

The need for regular mass anthropometric measurements of the feet of different population categories results from the gradual changes in the dimensional parameters and morphology of the feet of people, as well as modern requirements for certain types of footwear. Designing shoes based on the measurements of a foot and taking into account its shape will improve fitness (correspondence to the parameters of the foot) and make shoes more comfortable [1-3].

The current level of development of digital technologies and their wide range of applications require conducting anthropometric studies using the advanced contactless methodologies and high-tech equipment. 3D scanning allows obtaining information about the entire surface, dimensions, as well as all the sizes and cross sections of a body, as well as digital foot prints. The advantages of using 3D scanning of feet lie in the fact that it allows scanning large numbers of participants quite quickly and this type of measurement is reliable and efficient [4, 5]. The measurement results are stored as information files that are available for use at any time. The accuracy of the obtained data is higher than the accuracy of manual measurements.

The use of 3D scanning to obtain anthropometric information about a foot and study the compliance between feet and shoes is described in numerous scientific works and most researchers have focused on quantifying the degree of correspondence by comparing major parameters of the last with the anthropometric data related to the feet [6, 7]. Selection of the last that corresponds most to a customer's foot is carried out in a similar way [8].

Research conducted by Rossi and Tennant [9] explained which anthropometric measurements are most important for the fitness (correspondence) of footwear. Mochimaru [10], Luximon [11], as well as Borchers [6] used full 3D foot shapes to determine the degree of correspondence between feet and shoes.

However, in the publications, we have not found any reasonable methodologies and recommendations for designing the parameters of the dimensional shape of a shoe last based on the results of mass 3D scanning of the feet of certain population groups. Therefore, this became the main task of our work.

EXPERIMENTAL

Materials and Methods

The most progressive and effective method of anthropometric measurements is 3D scanning. In this work the feet were scanned using the InFoot 3D (OrthoBaltic, Lithuania), a specialized 3D scanner with an accuracy of 0.3 mm. During the scanning process, the person stood on their feet and their body weight was distributed evenly over the two legs. Both the right and left feet were scanned. As the results we received the files of three main formats: (a) a file with the digital copy of foot surface in STL format; (b) a file with the footprint in JPG format; and (c) a file with the main digital foot parameters.

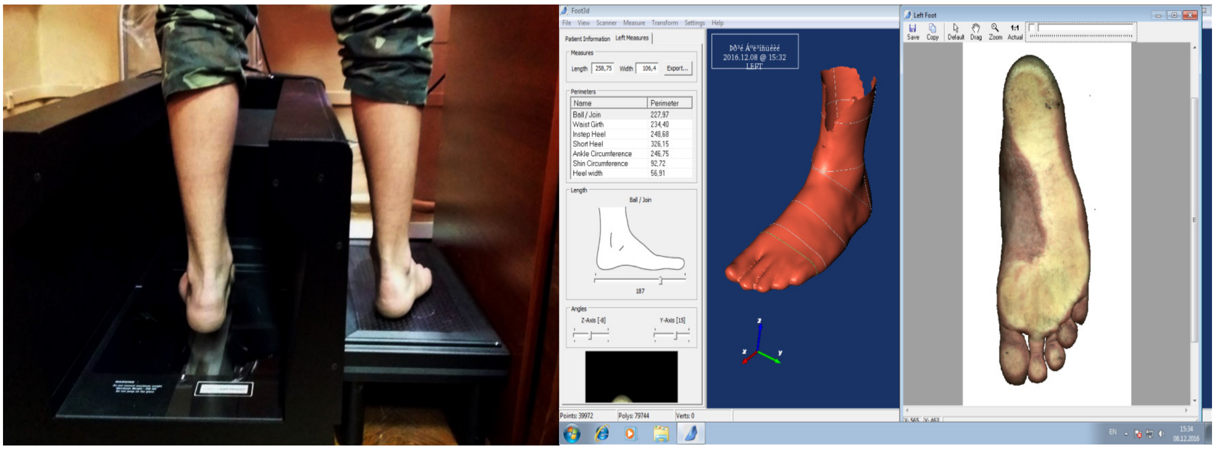


Figure 1. The foot scanning process using special 3D scanner InFoot 3D

The method of research of the feet anthropometric and morphological parameters applied in the work includes the parameters [3, 12] based on the main points of the foot showed in Figure 2.

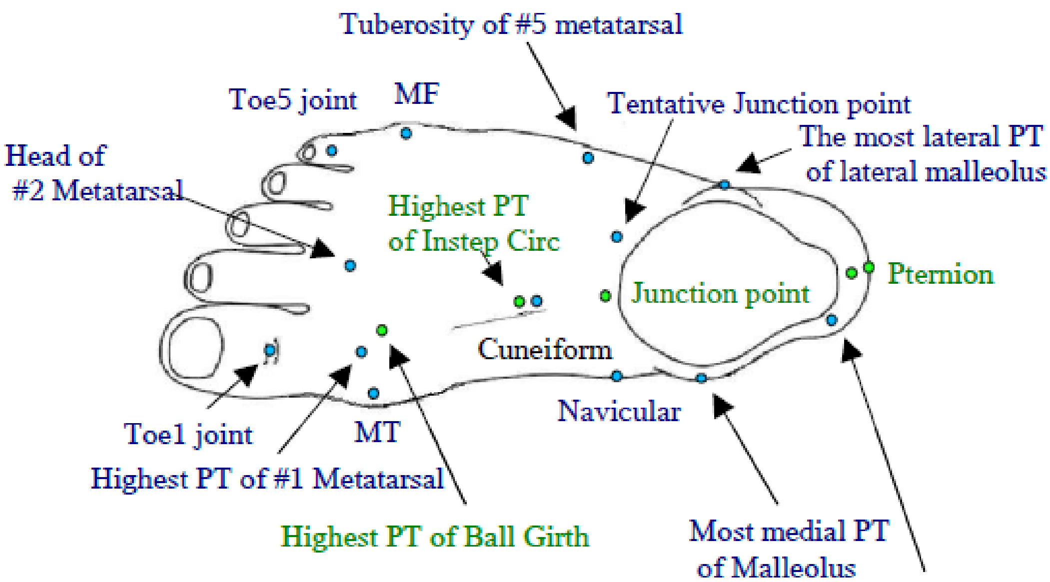
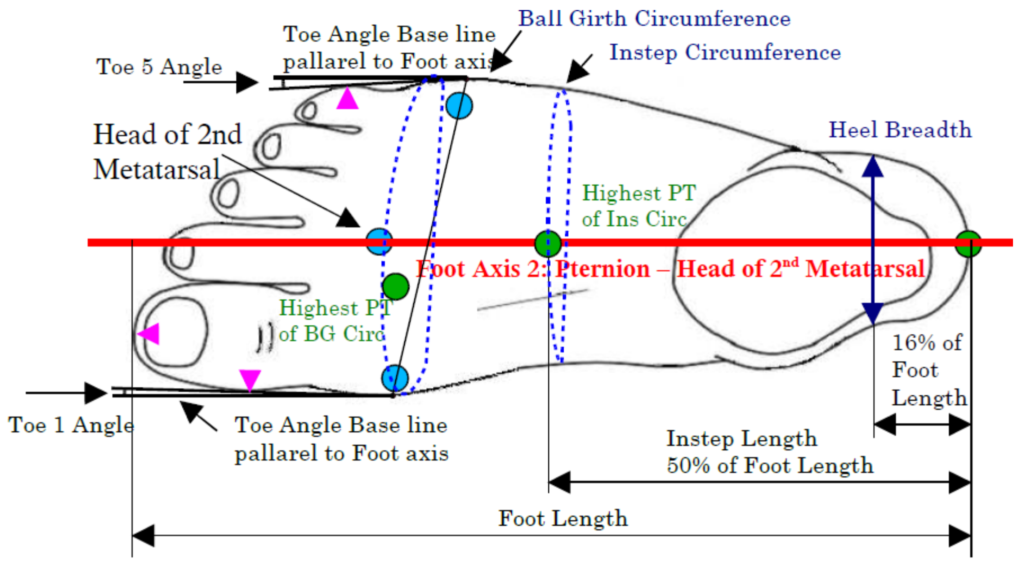


Figure 2. The main anthropometric points of the foot

Most parameters are obtained on the basis of a digital 3D model of the scanned foot (Figure 3): They include length, width, girth and height values according the main anthropometric points.



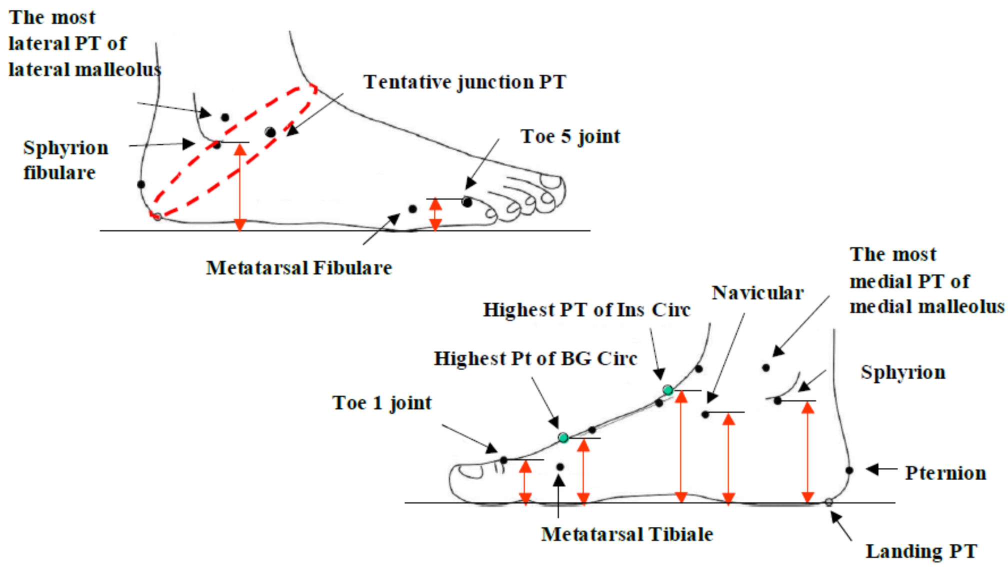


Figure 3. The main anthropometric parameters were measured on the feet

The latitudinal and longitudinal dimensions required to design the contour of the footprint are more convenient to determine on the basis of a footprint, which is obtained automatically when scanning the foot on a specialized 3D scanner. The method of footprint analysis involves determining the parameters associated with the shape and size of the outline and imprint (Figure 4). Popular graphics programs for working with vector graphics (AutoCAD, Corel Draw) were used to calculate the needed parameters and analyze the footprint.

In addition to the parameters of width, girth and length (Figure 4), it is necessary to obtain the angular dimensions of the foot to form the ergonomic shape of the insole (which corresponds to the shoe last bottom surface):

- the angle of deviation of the hallux;
- heel position angle;
- the angle of the foot position.

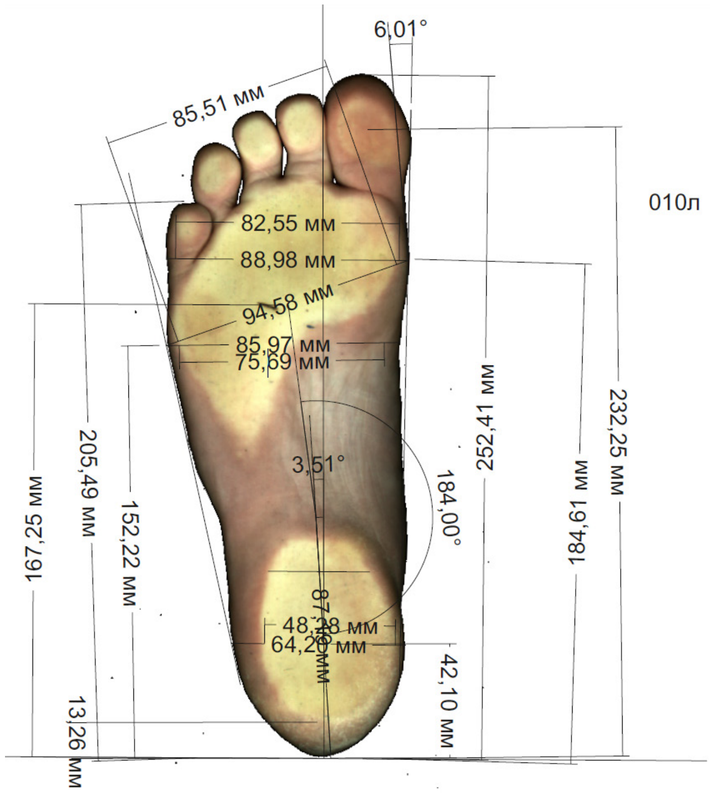


Figure 4. Definition the parameters of the foot on the basis of the footprint

To determine the height and circumference parameters, it is necessary to use the functions of graphic 3D programs (Figure 5). PowerShape software was used in this work.

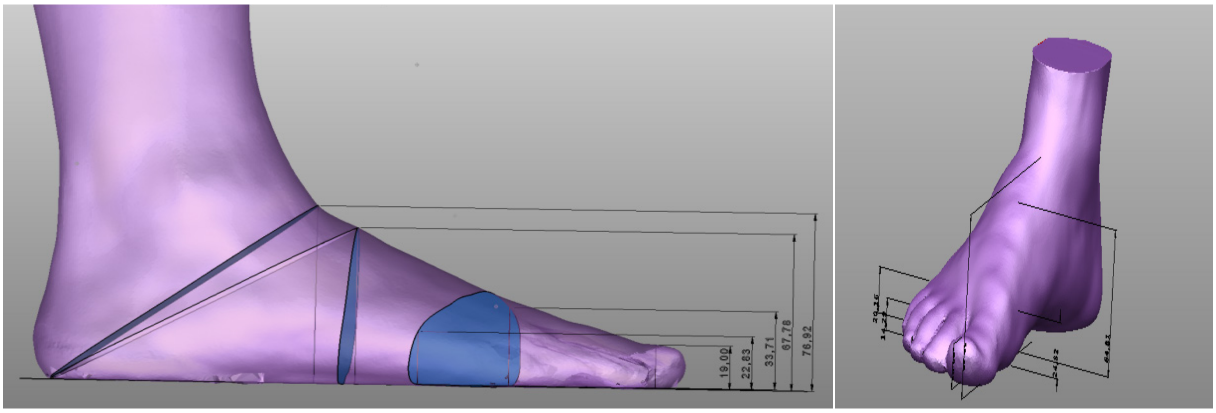


Figure 5. Definition the height parameters of the foot on the basis of measuring the foot 3D model

RESULTS AND DISCUSSIONS

The sample size for anthropometric studies consisted of 254 people. The sample is homogeneous; it includes young men aged from 21 to 30 years, without significant foot pathologies. According to the research results, the minimum (min) and maximum (max) values of the foot length in the sample (min = 243 mm, max = 301 mm) were defined.

As a result of the measurements made in the context of the experiment, the arithmetic mean values (M) of dimensional features and their root-mean-square deviations (Table 1) were obtained for the feet of men aged from 21 to 30. These values can be used to design products and develop a dimensional typology.

Table 1: Arithmetic mean values (M, mm) and root-mean-square deviations (σ, mm) of the dimensional features of the feet of men aged from 21 to 30 who are from different regions of Ukraine

Dimensional Feature	Arithmetic Mean Values (μ, mm)	Standard Deviations (σ, mm)
Foot length	271.41	10.59
Balls girth	255.69	12.14
Short heel girth	345.36	18.05
Outer ball girth	250.01	18.28
Inner ball girth	248.21	11.85
Instep girth	269.16	15.55
Ankle girth	265.68	17.72
Sn (distance from the contour to the imprint of a heel)	11.79	3.65
D 0.18 (distance to the center of a heel)	45.723	3.78
D 0.62 (outer ball part)	166.82	7.01
D 0.73 (inner pall part)	202.02	5.90
D 0.68 (middle of the ball parts)	176.58	14.93
D 0.8 (tip of the fifth toe)	223.92	6.63
D 0.9 (the middle of the first toe)	257.16	5.49
Heel width (based on the contour)	62.67	5.06
Heel width (based on the imprint)	51.79	5.91
W 0.62 (based on the contour)	94.75	4.91
W 0.62 (based on the imprint)	88.27	4.62
W 0.73 (based on the contour)	95.17	4.37
W 0.73 (based on the imprint)	86.02	5.42
W 0.68 (based on the contour)	106.33	6.17
W 0.68 (based on the imprint)	97.80	4.65
<L	9.93	4.09
<m	9.20	10
<n	168.02	7.26

A complex three-dimensional shape of the foot is characterized by many morphometric components. Some of them appear to be the most significant ones [12] and they define the limits of variation of the foot shape (± 3σ) based on the studied population. These variations should be taken into account when designing the last parameters and calculating the range of dimensions and fullness parameters.

Thus, high variability of such an important parameter as the width of the ball parts, as well as their girth, indicates the need to develop a complete range of lasts and shoes based on their fullness within single size.

In order to assess the differences in the morphological structure of the feet of the same size, it is first necessary to align digital foot models according to a single coordinate system. The longitudinal axis passes through the projection of the pternion point onto the support area and the first inter-toe gap [3].

While analyzing the 3D shape of young males' feet, we have identified the parameters that most clearly characterize the differences in the morphological structure of the foot, which affects the shapes and sizes of the lasts:

- ball width;
- inner and outer ball girth;
- height of the longitudinal arch of the foot;
- width and girth of the midfoot;
- deviation angle of the first toe;
- position angle of a foot;
- distance between toes (the width of toe area);
- the height of the head of the first instep bone;
- the height of the first toe.

One of the most variable parameters with significant dispersion is the width of the foot in the ball parts and ball girth. This is the second major parameter that determines the correspondence of shapes and sizes of a last to a foot. According to the results of the anthropometric studies, the difference in the girth of the foot in this area can reach 30 mm for certain length of a foot. Thus, for the average length of the foot among the studied population (270 ± 2.5 mm), the inner and outer ball girths ranged from Bgmin = 244.3 mm to Bgmax = 270.1 mm. The average girth of the balls was 256.5 ± 12.14 mm. Comparison of the shapes of narrow, medium, and large feet is presented in Fig. 6.

The foot width and the ball parts girth are crucial for calculating the width of a last. Based on the results of the research and the recommendations of industry standards, there should be at least three fullness values of a last of certain size (narrow, standard, and wide ones).

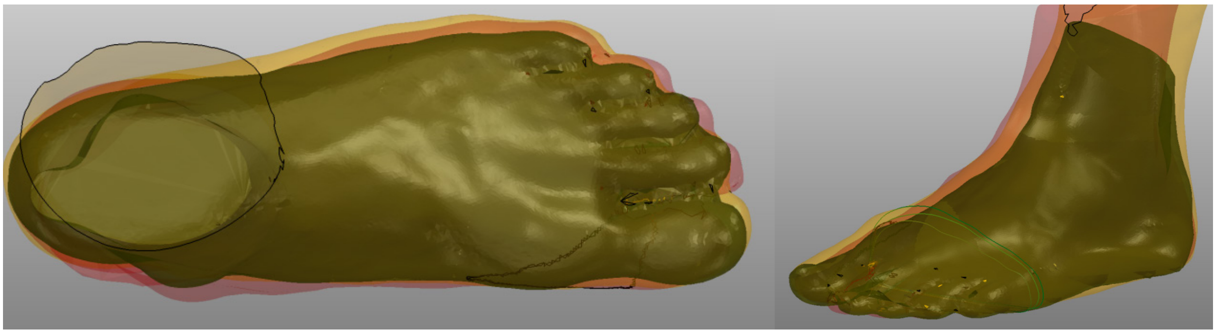


Figure 6. The comparison of 3D models of medium-sized feet with different ball widths

The foot print, which was obtained automatically during the study when scanning the foot, is very indicative for the characterization of foot morphology. According to a foot print, a large number of the most important morphological indicators are defined. One of these indicators is the position of the foot (normal, abducted or adducted one) and it is determined according to the angle between the axis of symmetry of the heel part and the axis of the front part of a foot. In the studied sample, this angle ranged from 152 to 187° (Figure 7).

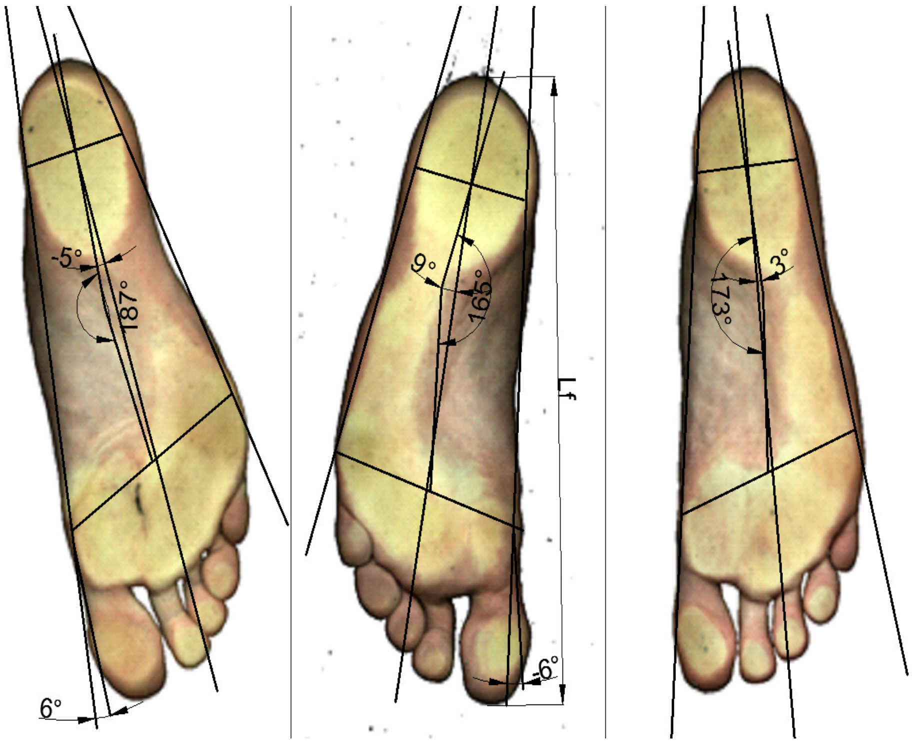


Figure 7. Defining the major angle parameters based on the most typical foot prints of the average-sized feet

While analyzing the shape of the toe section, we have noticed the significant variability of the parameters of the angle of the first toe. Individuals with the high values of this angle had the feet with hallux valgus, while low values of this angle characterized the feet with hallux varus. The average value of the angle, which is typical for a normal foot, ranges between 4 and 8 degrees. The angle parameter of the first toe is also subject to the law of normal distribution.

According to the results of the conducted studies, the most common deformities of the feet of young men were longitudinal flatfoot of various degrees (up to 40% of the measured feet), claw toes (about 20% of the measured feet), hypertrophy of the heads of the 1st metatarsal bone (about 30% measured feet), fan-shaped toes (20% of the feet), hallux varus, hallux valgus, and the fifth toe muscles hypertrophy (32% of the feet). Hypertrophy of the head of the 1st metatarsal bone is often combined with hallux valgus. The onset and development of the head of the 1st metatarsal bone and the deformity known as the "claw toe" are most often caused by the use of inadequate shoes. Such deformity as the fifth toe muscles hypertrophy usually results from the adaptive changes in the morphological structure of feet of the young men engaged in certain sports (in our case, a significant number of men play football, go skiing, and do gymnastics).

When designing the lasts for the mass consumer of the studied sample population, it is necessary to focus on the typical average feet with consideration of each of the studied parameters [3, 11, 13]. However, if it is observed that there are a large number of similar deformations or deviations of a parameter that is important in terms of anthropometrics, this should not be ignored. Thus, during measurements, it was noticed that a large number of men had hypertrophy of the heads of the 1st and 5th metatarsal bones. On the other hand, the fact that there is a considerable percentage of feet with large balls requires the increased parameters of the ball section of the last. In order to rationalize the range of lasts with different sizes and fullness, while trying to fully satisfy the requirements of compliance with the anthropometric parameters of the feet of consumers, it is considered effective to take into account the parameters of the feet with the hypertrophy of the heads of the 1st and 5th metatarsal bones in the lasts with significant fullness. Given the large difference in the girths of the ball areas of the feet of the studied population, the lasts are to be made in accordance with at least two width values for each size (standard and wide ones).

The following basic requirements should be adhered to when designing lasts. The toe area of the foot should not be squeezed by the shoe since there is a hard toe box in this place which will have a painful effect on the foot, therefore, in the toe part, the last bottom surface must take into account the parameters of the wide shape of the toe area of the foot. The height of the last at the level of the first toe is calculated based on the greatest height of the toe in a certain size class. At the level of instep part, the width and girth of the last are calculated based on the average parameters for each size. For the flat foot, it is possible to additionally apply a profile insole that partially compensates for the excess space inside the shoe. For a foot with the high instep, it is sufficient to adjust the tightness of the laces on the army boots.

The basis for the construction of the frame of the complex 3D body of the last is the contour of its bottom surface [3]. The last bottom surface is designed on the basis of averaged foot print of a certain size class. However, given that our task is to develop an ergonomic last shape that will meet the requirements of convenience of the maximum number of consumers, we must also take into account the parameters and peculiarities of the morphological structure of the most common types of feet. Apart from that, we need to develop a single shape of a last (which will be of the medium size and with medium fullness) that will fit most of the existing morphological types of the feet of the studied category. The following are some of the morphological features that influence the shape of the last and affect a significant part of the target consumer segment: the hypertrophy of the heads of the 1st and 5th metatarsal bones; fan-shaped toes and hallux varus; the fifth toe muscles hypertrophy. These are the deformities that result in the changes in the anthropometric parameters of the foot and cause discomfort when they are ignored in the inner shape of a shoe. To build the basic contours of the last frame, we selected 3D models and foot prints which reflect the most common morphological types. Thus, Fig. 8 presents the comparison of 3D models of medium-sized feet with the average fullness that have the following common morphological features: the fifth toe muscles hypertrophy, which is indicated with the green color, the hypertrophy of the head of the 1st metatarsal bone, which is indicated with the purple color; and fan-shaped toes, as well as hallux varus, which are represented with the yellow color.

Figure 9 represents the comparison of the contours of the last bottom surface of a medium-sized shoe, which is designed on the basis of mass anthropometric studies of the feet of young Ukrainian men. The last bottom surface designed based on the print of the average-sized foot that has no deformities is indicated with the red contour. The last bottom surface designed with the consideration of the common morphological peculiarities is indicated with the black contour.

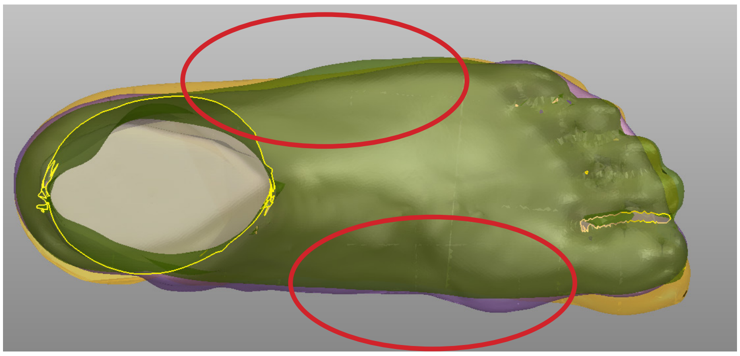


Figure 8. The comparison of the 3D models of average-sized feet of different morphological types

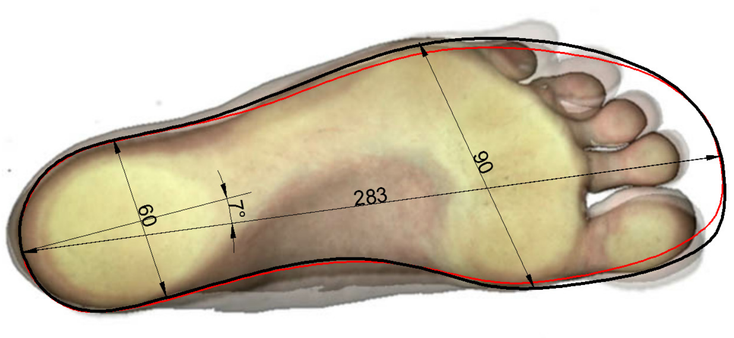


Figure 9. The comparison of the last bottom surface contours designed based on the foot prints with and without the consideration of common deformities

Based on the results of anthropometric studies, the parameters of a last of the average size (270 mm) with two width values (Table 2) were developed.

Table 2: The parameters of the feet and lasts with the medium and large fullness

Dimensional feature	Arithmetic mean value, μ, mm	min according to the average dimensional interval, mm	max according to the average dimensional interval, mm	The last of the medium width, mm	The last of the wide width, mm
Foot length	271.4	268.9	272.2	290	290
Foot length (based on the imprint)	262.1	260.3	265.2	283	283
Ball girth	256.5	244.3	270.1	256	268
Short heel girth	349.6	342.2	370.0	360	372
Instep girth	267.2	249.8	275.7	268	280
Ankle girth	267.1	253.5	282.2	270	282
Heel width (based on the contour)	63.5	56.8	70.5	67	71
Heel width (based on the imprint)	51.79	45.5	60.1	60	63
Ball width (based on the contour)	104.5	99.0	110.3	96	101
Ball width (based on the imprint)	97.8	93.0	102.1	90	94
Height of the first toe	23.5	20.1	26.8	27	28
Ball cross section height	45.4	42.1	49.8	48	54
Last height at the level of the short heel	86.7	79.8	93.1	92	99

Figure 10 presents the sequence of obtaining the necessary data for the design of the last shape on the basis of mass anthropometric studies of the feet of the selected sample population, which was carried out using 3D scanning of the feet.

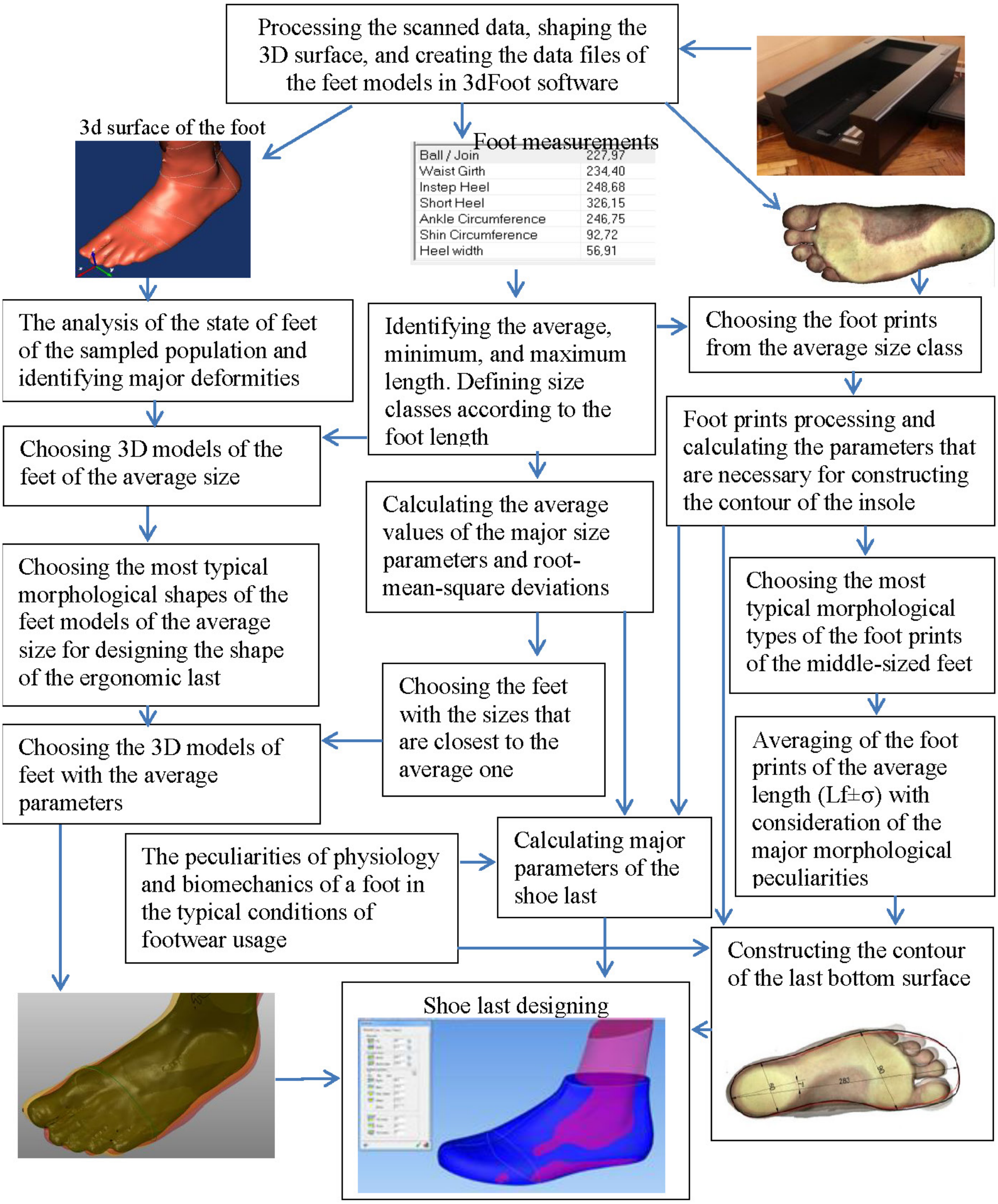


Figure 10. The algorithm of developing the ergonomic last shape for military footwear

CONCLUSIONS

Analyzing the quality of domestically produced military footwear, consumers highlight that it is not comfortable enough. The fact is that domestically produced military boots are manufactured either on the outdated lasts of the Soviet model of the 70's, or on random lasts, the shape of which is not substantiated from the anthropomorphological point of view.

In the work, anthropometric studies of the feet were performed by means of 3D scanning. The results of scanning have been used for two main purposes. Firstly, there were studied the features and morphological structure of the feet of young men aged 20-30, who are the representatives of the Ukrainian population that are subject to mobilization into the ranks of the Armed Forces. Apart from this, the quantitative distribution of the main morphological features of the feet of the sample population was analyzed. During measurements, it was noticed that a large number of men had hypertrophy of the heads of the 1st and 5th metatarsal bones. On the other hand, the fact that there is a considerable percentage of feet with large balls requires the increased parameters of the ball section of the last. In order to rationalize the range of lasts with different sizes and widths, while trying to fully satisfy the requirements of compliance with the anthropometric parameters of the feet of consumers, the parameters of the feet with the hypertrophy of the heads of the 1st and 5th metatarsal bones must be taken into account in the lasts with increased width. Furthermore, the results of scanning constitute the basis for calculating and developing basic parameters of lasts. For this, the work suggested the method of designing a last shape based on such types of input data as a digital foot model, dimensional foot parameters, and a foot print obtained as a result of mass 3D scanning of the feet.

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FUNCTIONAL FOOTWEAR DESIGN FOR PREVENTING FALLS IN THE ELDERLY: A SYSTEMATIC RESEARCH BASED ON FAULT TREE ANALYSIS

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FUNCTIONAL FOOTWEAR DESIGN FOR PREVENTING FALLS IN THE ELDERLY: A SYSTEMATIC RESEARCH BASED ON FAULT TREE ANALYSIS

ABSTRACT. The purpose of this research is to improve the elderly's footwear for preventing falls in walking. The design method of the footwear for the elderly was proposed based on fault tree analysis (FTA). There were four phases for improving the footwear. At first, the fault tree diagram was built by determining the causes of the elderly falling, literature review and user interview were applied at this phase. Then, both qualitative and quantitative analyses were conducted. The minimal cut sets of the elderly falls were identified. Besides, seven core risk factors were proven as strong or moderate influences for the falling issues, and which are related directly or indirectly to the elderly's footwear. Finally, the footwear optimizations were made, and the seven core risk factors were mainly considered in the design process. The proposed design method provided a series of specific steps to help to define the practical causes of the elderly falling. The improvements of the footwear were made reasonable in that way, as well as enabled an improved experience for the elderly users.
KEY WORDS: elderly, functional footwear, falls prevention

DESIGN FUNCȚIONAL DE ÎNCĂLȚĂMINTE PENTRU PREVENIREA CĂDERILOR LA VÂRSTNICI: O CERCETARE SISTEMATICĂ BAZATĂ PE METODA ARBORELUI DE DEFECTARE

REZUMAT. Scopul acestei cercetări este de a îmbunătăți încălțămintea pentru persoanele în vârstă cu scopul de a preveni căderile în timpul mersului. Metoda de proiectare a încălțămintei pentru vârstnici a fost propusă pe baza metodei arborelui de defectare. Îmbunătățirea încălțămintei s-a desfășurat în patru faze. La început, s-a realizat diagrama arborelui de defectare prin determinarea cauzelor căderii în cazul vârstnicilor; în această fază s-a studiat literatura de specialitate și s-au realizat interviuri cu utilizatorii. Apoi, au fost efectuate atât analize calitative, cât și cantitative. S-au identificat seturile de evenimente primare care conduc la căderi. În plus, șapte factori de risc fundamentali s-au dovedit a fi influențe puternice sau moderate pentru căderi, aceștia fiind corelați direct sau indirect cu încălțămintea purtată de vârstnici. În cele din urmă, s-a optimizat încălțămintea, iar cei șapte factori de risc fundamentali au fost luați în considerare în procesul de proiectare. Metoda de proiectare propusă a oferit o serie de etape specifice pentru a facilita definirea cauzelor practice ale căderii la vârstnici. S-au adus îmbunătățiri rezonabile încălțămintei, permițând astfel o experiență mai bună pentru utilizatorii în vârstă.
CUVINTE CHEIE: vârstnici, încălțăminte funcțională, prevenirea căderilor

LA CONCEPTION FONCTIONNELLE DE CHAUSSURES POUR LA PRÉVENTION DES CHUTES CHEZ LES PERSONNES ÂGÉES : UNE RECHERCHE SYSTÉMATIQUE BASÉE SUR LA MÉTHODE D'ANALYSE DE L'ARBRE DE DÉFAILLANCES

RÉSUMÉ. L'objectif de cette recherche est d'améliorer les chaussures des personnes âgées afin de prévenir les chutes lors de la marche. La méthode de conception de chaussures pour personnes âgées a été proposée sur la méthode d'analyse de l'arbre de défaillance. L'amélioration de la chaussure s'est déroulée en quatre phases. Au départ, le schéma de l'arbre de défaillance a été réalisé en déterminant les causes de la chute chez les personnes âgées ; dans cette phase, la littérature a été étudiée et des entretiens ont été menés avec les utilisateurs. Ensuite, des analyses qualitatives et quantitatives ont été réalisées. Les coupes minimales menant aux chutes ont été identifiés. De plus, il a été démontré que sept facteurs de risque clés ont une influence forte ou modérée sur les chutes, qui sont directement ou indirectement liées aux chaussures portées par les personnes âgées. Enfin, les chaussures ont été optimisées et les sept facteurs de risque clés ont été pris en compte dans le processus de conception. La méthode de conception proposée prévoyait un certain nombre d'étapes spécifiques pour faciliter la définition des causes pratiques des chutes chez les personnes âgées. Des améliorations raisonnables ont été apportées aux chaussures, permettant une meilleure expérience pour les utilisateurs plus âgés.
MOTS CLÉS : personnes âgées, chaussures fonctionnelles, prévention des chutes

INTRODUCTION

Falls among the elderly have widely drawn attention; WHO revealed a fact that approximately 684,000 people fall-related die every year worldwide, as well as people aged over 60 are more likely to take a higher risk [1]. Almost all falls happen when the body is in motion, and footwear is considered a significant risk. In recent years, there have been some footwear designs made to minimize the risk of falling. For example, Cheng *et al.* designed the smart shoes with tracking and the shoes were 3D printed to fit the deformation of the elderly's foot [2]; Aboutorabi *et al*. designed a vibrating system in the sole of the footwear to enhance the postural stability for the elderly [3]. Most solutions were individually targeted and technologies applied. However, WHO also indicated the risk of elderly falls could be caused by various reasons, including physical, psychological modifications of aging, and the external impacts [1]. However, present design concepts were based on less comprehensive consideration. Thus, it is necessary to investigate elderly falls in a comprehensive manner and propose an integrated design.

Fault tree analysis (FTA) is a significant method for a comprehensive investigation. As a practical technique, FTA can be applied to determine relevant potential causes of the system failure in a deductive way, which would be helpful for enhancing the reliability and safety of the system. FTA has been widely used for predicting possible equipment failure, planning maintenance, and evaluating risks. One typical research from the department of Kaiserslautern University, is that fault tree construction was applied to analyze and improve the safety of ambient assisted living for the elderly [4]. FTA allows the designer to investigate how module defeats lead to system undesired events happened in the context of the environment and operation, and then the results would help to improve the design [5]. In this study, a fault tree is proposed to identify the causes of elderly falls from both internal and external aspects. External factors include unsuitable shoes and environmental effects. Internal factors include psychological and physiological causes. Falls among the elderly as an undesirable failure in the fault tree and which is broken down into every basic fault inputs. All basic fault inputs are analyzed in terms of both quality and quantity. The results of FTA are presented as an expose of their interrelations and an importance ranking, and the results are applied in the footwear design comprehensively.

This paper aims to evaluate the ultimate causes of elderly falls by the method of FTA, and thus propose an integrated solution of elderly functional shoes. The logic deduction of causes would be conducted and represented on the fault tree diagram. The diagram shows the root of the problems, and which helps the designer to exam the ultimate causes of falls. Based on this, FTA is applied to the footwear design for qualitative and quantitative analysis of elderly falls. After the critical causes of failure are identified, the solutions would be proposed with shoes toward those causes. This study will give a reasonable solution to elderly falls as well as a useful reference for the optimization of footwear design.

METHODOLOGY

Fault Tree Analysis

The fault tree model is a graphical way that demonstrates how failures are caused through logical decomposing of the undesired event into basic events. It allows the designer to analyze the product in the context of the user, environment, and operation to figure out entire reliable causes why the undesired event happen [5]. The faults could connect to the components defeats, human faults, or other environmental problems. Therefore, a fault tree can be applied to present the logical interrelationships between basic events and the undesired event that they led. Each event of the tree is connected by the gates as a logic flow. The top event is the output of the tree, and basic events are the inputs of the tree.

However, considering a complex system investigation, it could be plenty of events and combinations. The fault tree can not only draw quantitative results, but also qualitative results. Quantitative measurements are applied to calculate the failure probability of the basic events. Based on the measurements, the basic events would be sorted by correlation, from greatest to least.

Thus, FTA is applied in this paper, aims to determine the causes of elderly falls in the context, and helps to improve the footwear design for the elderly to prevent from falling.

Fault Tree Construction for Elderly Falls

This study presents an optimum footwear design for the elderly to prevent falling based on analyzing a fault tree. Concerning relevant factors of elderly falls, the structure and materials of shoes would be enhanced to more accommodate the elderly's behavior and minimizing the falling risk. Figure 1 presents the flow of developing and analyzing the fault tree of elderly falls, which are described in the following subsections.

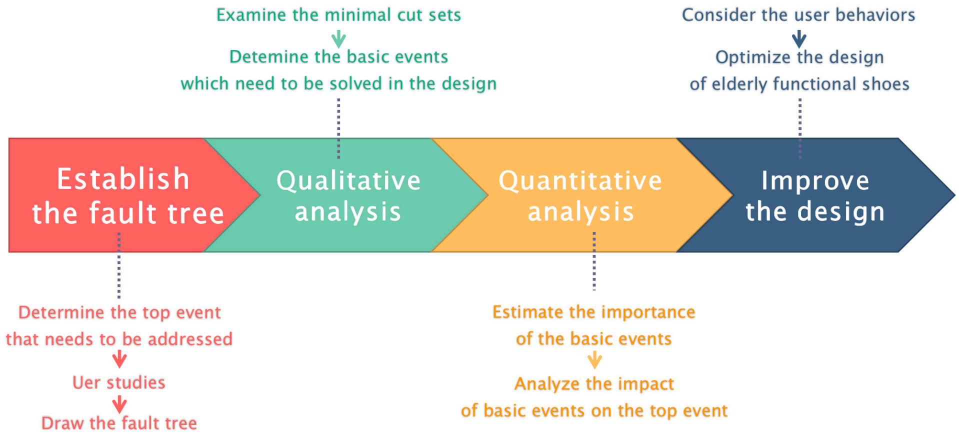

Figure 1. Research method flow

Establish the Fault Tree

As shown in figure 1, there are three steps to build the fault tree model.

At first, it is to choose the top event carefully. The top event as an undesired event is deduced in the fault tree diagram to figure out causes. The top event could not be overall or too specific due to the investigation must be manageable and wide viewed [5]. From the above considerations, falls among the elderly are a suitable undesired event for fault tree analysis.

The second step of this stage is to fully understand the causes of elderly people's falls. The literature review and interview were applied at this step. Literature review is mainly focused on the risk factors for elderly falls, categorizing personal specific and extrinsic reasons [6]. Personal reasons involve physical and psychological factors [7]. Extrinsic reasons refer to environmental factors such as poor lighting, slippery staff, as well as unsuitable footwear [8]. A detailed illustration of the risk factors would be shown in the next section of the results and discussion. Thus, based on the results of the literature review, the questionnaire is designed, and interviewed 20 old people. The questionnaire is given in the appendix, and Informed consent which were signed by all study participants was attached. Besides, the results would be further discussed in the results section.

After deep learning of elderly falling causes, the fault tree model could be constructed by the deductive method. The fault tree model is constituted by symbols that represent different incidents. The top event is in the uppermost rectangle, followed by the intermediate events which are also in the rectangle, and the basic events are in the circle at the bottom. The intermediate events are those faults that happened and can be broke down into further factors, and the basic events describe those faults which require no more decomposition. However, there is one kind of undeveloped event which is described by the diamond that would not be decomposed further since the unavailable information is related. All events are connected by the gates in the fault tree. There are normally two types of gates, including the AND-gate and the OR-gate. The OR-gate is applied to represent that only if one of the lower events occurs would lead the upper event occurs. The AND-gate is applied to represent that only if all the lower events occur would lead to the upper event occurs. The fault tree model of elderly falls is produced and would be introduced in the section of results.

Qualitative Analysis of the Fault Tree

The purpose of qualitative analysis is to identify the minimal cut sets of the fault tree, which are all the unique combinations of basic events that cause the top event failure. In other words, if one of the combinations fails, the system will fail. However, not all factors can be controlled and optimized in the footwear design, especially some external factors such as loss of concentration [6]. For those non-repairable factors, there are no more considerations in this footwear design. The more specific factors will be discussed in the next section of the results.

Thus, there are two steps to qualitative analysis, including minimal cut sets definition and determination of the major basic events which would be solved in the stage of improving the design.

Quantitative Analysis of the Fault Tree

After the major minimal cut sets are determined, the relevant probability can be evaluated by quantitative analysis. The quantitative analysis is normally performed by a mathematical approach [5]. Through surveys to obtain the basic events failure probabilities, as well as the probabilities of the minimal cut sets, and then the probability of the top event failure can be calculated. For a fault tree with every independent minimal cut set, the probability of the top event failure is the sum of all the minimal cut sets failure probabilities. However, for the case of elderly falls, it is tough to measure the basic failure probabilities by actual surveys. Therefore, the literature survey is applied to determine the failure probabilities of the basic events. The evaluation results are represented in the strength of evidence, including strong, moderate, and low. The degree of strong means the basic event is described in multiple studies, and at least two descriptions are prospective. The degree of moderate means the basic event is described in various studies, and only one description is prospective. The degree of low means the basic event is described in few studies, and no one of the descriptions is prospective.

To improve the footwear design more effectively, it is necessary to screen out the basic events which are critical for improvement. Since each basic event performs differently on the top event, as well as the impacts. In this study, mainly considering the basic events in which grades are strong or moderate, which would be analyzed associated with shoe parts. The outcome of this stage would be a ranking of screened basic events.

Design Improvement

Based on the results of quantitative analysis, the improvement of the shoe is mainly focused on the structure, material, as well as accessories. The structure of the shoe is split into seven parts to be modified, including outsole, midsole, insole, stiffener, heel, toe box, and upper. The functions of the shoes would be modified reasonably for the elderly to prevent them from falling. Besides, when they are wearing the shoes, the shoes should conform to their wearing habits. Therefore, the biological, psychological, and emotional changes of the elderly should be considered fully when improving the footwear design. To avoid causing other serious damage of the elderly wearing shoes, the finely balanced decision would be taken.

Following the four phases described above, approaches to reducing elderly fall risk by enhancing the footwear design were proposed, and the detailed results are discussed in the next section.

RESULTS AND DISCUSSION

Fault Tree Analysis

To establish the fault tree of elderly falls, not only the potential causes would be investigated, but also the deeper causes. as well as the interrelationships, should be identified. Thus, methods of literature research and interview were applied.

From literature research, falls among the elderly are prominent for unintentional injury. Elderly falls always occur for complex reasons [9], which has been documented in many studies. Risk factors of elderly falls are regularly classified into intrinsic causes and extrinsic causes [10]. Intrinsic causes include psychological and physiological factors such as loss of concentration, foot deformity, poor posture control, and medical causes [7]. Extrinsic causes refer to most hazards around such as poor lighting, slippery floor, and unsuitable shoes [8]. As the number of factors mounted, the risk of elderly falls would become higher [11].

20 old people aged 60-80 participated in this survey, including 10 males and 10 females. A questionary was designed to collect the relevant information. It was mainly to investigate the potential risks, current health conditions, any measurements taken, whether the fall occurs and consequences. The relevant questions and results statistics were attached, as well as keep their personal information confidential. 55% of participants suffered multiple injurious

falls, and six of them fell more than once. From their recalls, the causes were tripping hazards, loss of concentration, dizziness, low muscle strength, lack of grab bars, limited vision, and poor balance. Besides, 60% of participants have a distinct foot deformity, and they prefer shoes soft and loose.

Based on the results of the literature review and interview, the factors that could lead to elderly falls were cataloged. All causes were deduced from the top event to the basic events to identify the implicit causes. The causes of elderly falls could be divided into categories of external problems and internal problems. The external problems include environmental effects and unsuitable shoes. The internal problems include psychological factors and physiological factors. Those intermediate events would be further deduced level by level until the basic fault events are identified. After all basic events were identified, all events would be connected by the gates. The complete fault tree of elderly falls while walking outdoors is shown in figure 2.

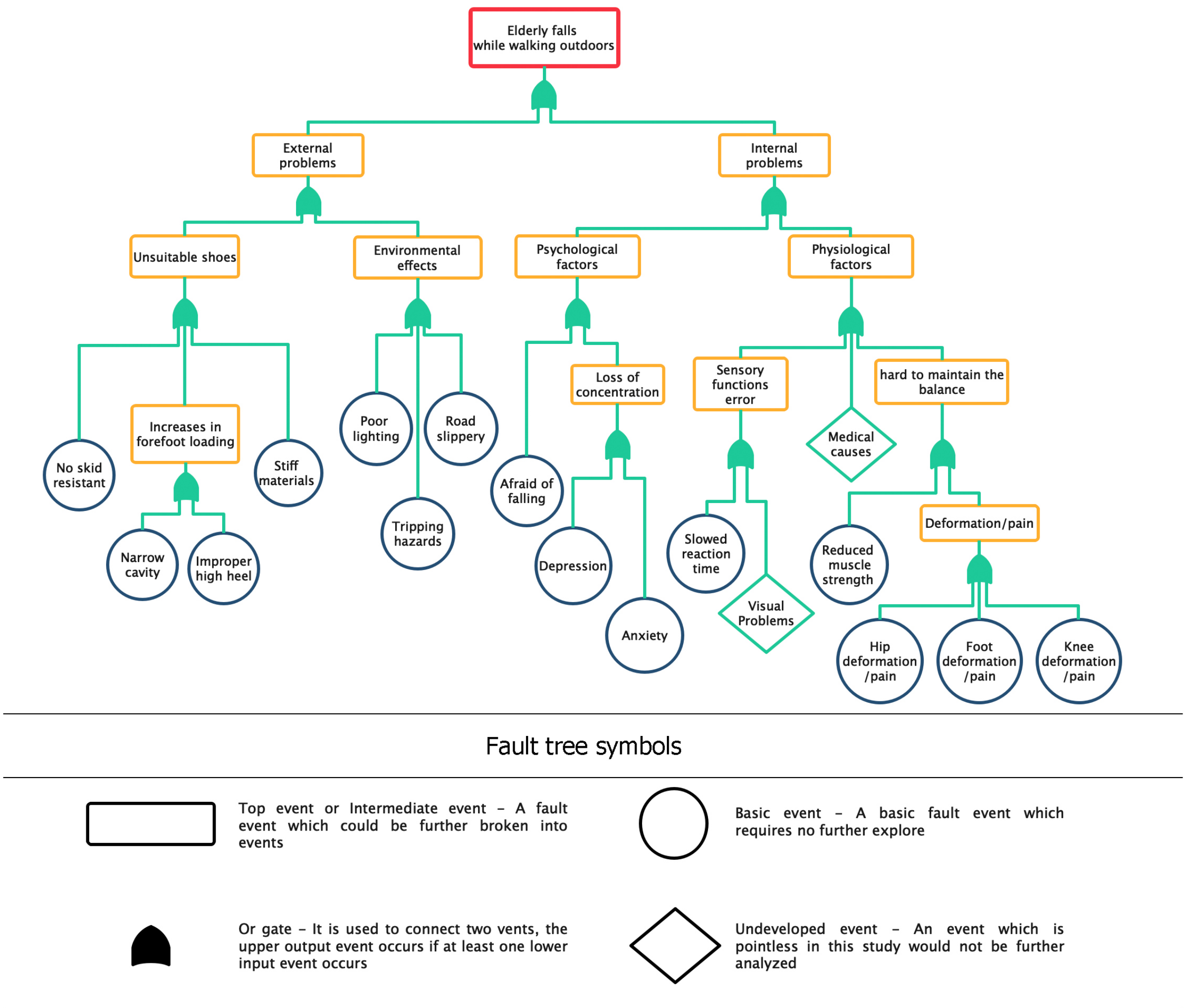

Figure 2. Fault tree of elderly falls while walking outdoors

Qualitative Analysis

Qualitative analysis is principal start from top event to basic events, to sort through the logical relationships between top event and basic events. Thus, the minimal cut sets would be identified which are all basic causes combinations of top event occurs. The fault tree of elderly falls while walking outdoors has 17 minimal cut sets, which are shown in Table 1. Every single basic event from minimal cut sets occurs would lead to elderly falls occur.

Table 1: The minimal cut sets of the fault tree

Num.	Minimal cut sets	Num.	Minimal cut sets
1	No skid resistant	10	Anxiety
2	Stiff materials	11	Slowed reaction time
3	Narrow cavity	12	Visual problems
4	Improper high heel	13	Medical causes
5	Poor lighting	14	Reduced muscle strength
6	Tripping hazards	15	Hip deformation/pain
7	Road slippery	16	Foot deformation/pain
8	Afraid of falling	17	Knee deformation/pain
9	Depression		

At this phase, the qualitative analysis could target the deep causes of elderly falls, and it calls for special concern in the footwear design. For example, the narrow cavity of shoes tends to make the elderly uncomfortable while walking, and less coordination of elderly would be knocked down easily.

However, there is no direct correlation between some unchangeable faults and elderly footwear improvement, especially the environmental situations and some body conditions. Environmental causes include poor lighting, slippery road, and tripping hazards. The effective way to mitigate the risk of falling from environmental causes is to create an elderly-friendly living environment, and a study from Jung shows that a safe living environment could help the elderly to reduce fear and anxiety from falling [12]. As for the causes of using medicines, elderly people tend to take all kinds of medicines to get healthy. The falling risk would be increasing if the prescriptions are not from professionals directly, because some non-adherence drugs would cause dizziness, stiffness, or judgment errors [9]. In addition to the faults associated with feet, the faults associated with other parts of the body would be not analyzed anymore in this study.

Thus, for optimal elderly footwear improvement, the minimal cut sets of environmental factors, medical causes, slowed reaction time, visual problems, hip deformation/pain, and knee deformation/pain would not be discussed anymore in the following analysis.

The basic events which would be modified in the elderly footwear improvement are shown in Table 2.

Table 2: The minimal cut sets which would be solved in the stage of improve the design

Num.	Minimal cut sets	Num.	Minimal cut sets
1	No skid resistant	7	Depression
2	Stiff materials	8	Anxiety
3	Narrow cavity	9	Reduced muscle strength
4	Improper high heel	10	Foot deformation/pain
5	Afraid of falling		

Quantitative Analysis

The main task of quantitative analysis is to obtain the probabilities of the minimal cut sets. Based on the literature review, the probabilities of each minimal cut set would be determined in the strength of evidence and the results are shown in Table 3.

There are six minimal cut sets that are strong predictors of elderly falls, including two factors with shoes, reduced muscle strength, and foot deformation/pain. The risk factor of shoes with non-skid resistance has been described in numerous studies strongly, and the studies show that anti-slip shoes can reduce fall risks and are suggested for elderly walking outdoors [13-17]. The risk of shoes with a narrow cavity is mainly concerned with foot pain in elderly people. Studies indicated that 26-50% of elderly people wear short or narrow shoes, and shoes are narrower than the foot due to foot deformity and pain [19-22]. Besides, tight shoes in the forefoot could cause gait to become unsteady and walking speed to decline [23]. The risk of shoes with improper high heels is associated with increased forefoot pressure and impaired balance for the elderly [19, 24, 25]. Besides, the experimental results show that high heels led to sway in a 16% increase rate compared to the flats [26]. Reduced muscle strength is associated with the movement of elderly people, the muscle force needs to be generated to control the movement in the balance performance [6]. The review indicated that low extremity weakness is a significant factor of falling [36]. The factor of foot deformation/pain is mainly associated with postural stability and impaired balance [37, 38]. Longer and wider feet of the elderly can help to improve postural stability, deformations of foot arch would affect postural stability, and the hallux valgus deformations would reduce postural stability [39].

Two risk factors were identified as moderate strength of evidence, including shoes with stiff material and depression. Shoes with stiff materials which are unsuitable for the elderly's painful feet and foot deformities have been described in several studies, which also indicated that the elderly would prefer shoes with soft material [13]. Besides, some studies specified that the hardness could enhance balance, and suggested suitable footwear with thin, hard soles for the elderly to wear [18, 19]. For the psychological factors, depression is support by moderate evidence. Depression was evaluated as an impaired cognitive function that is associated with increased risks of falls in multiple studies [31]. A study shows that the falls risk of depressed elderly people is higher than elderly without depression [32]. However, whether the metal impairments related to the psychomotor causes are still uncertain.

Two psychological factors include fear of falling and anxiety were low evidence of causes for falls. Afraid of falling means elderly people lose confidence in their ability to walk or stand [27]. There are several studies indicating that health status is related to the fear of falling, and this is a risk factor of activity restrictions [28, 29]. It is likely that elderly people with impaired gait would have a greater risk of fear of falling, fear of falling would also result in depression for elderly people [30]. However, none of the descriptions prospectively shows that fear of falling would lead to falling. From previous studies, anxiety may impact the risk of falls. Some studies examined the relationship between anxiety and fall, the results are different based on different types of anxiety and sex [33-35]. Thus, more information is required to determine the association between anxiety and falls among the elderly.

Table 3: Strength of evidence for the minimal cut sets

Num.	Minimal cut sets	Strength of evidence
1	No skid resistant	Strong
2	Stiff materials	Moderate
3	Narrow cavity	Strong
4	Improper high heel	Strong
5	Afraid of falling	Weak
6	Depression	Moderate
7	Anxiety	Weak
8	Reduced muscle strength	Strong
9	Foot deformation/pain	Strong

Improve the Footwear Design

Based on the results of quantitative analysis, the minimal cut sets in which the evidence strength are strong or moderate would be mainly considered in the improvement. The risks of elderly falls include shoes with non-skid resistance, shoes with stiff materials, shoes with a narrow cavity, shoes with improper high heels, depression, reduced muscle strength, and foot deformation/pain would be solved in this improvement.

At first, the risk factors of strong prediction were emphasized. For the slip resistance consideration, choosing both material and pattern shape must be careful. The thermal plastic rubber (TPR) outsole performs well in most slippery conditions to keep elderly people away from slip [40]. The pattern shape is responsible to grip the floor, the prominent hackle type would be applied and then repeating on the outsole. For the risk factor of the narrow cavity, which is also associated with the causes of foot deformation/pain. The cavity of shoes should be adjusted to fit the foot deformations from the elderly. The most common foot deformations include hallux valgus foot, foot arch collapse, and toe deformities [13]. The toe cap cavity would be adjusted wider at the metatarsophalangeal joint and toes with material softening. The insole would contain a hard piece at the foot arch to support the arch. Considering the high heel could lead to forefoot loading increased and balance impaired, the flat outsole would be applied. The risk factor of reduced muscle strength is highly associated with elderly falls. There are several studies that tried to solve this issue by textured or vibration insoles [41, 42]. However, the study also indicated that the investigation of the prolonged effects still remains [43]. At this phase, to help the elderly to keep balance better, a flared sole would be applied in the design.

The two moderate risk factors of falls involve shoes with stiff materials and depression. The upper material choice is a laminate with carbon fiber, the carbon fiber could provide spring and strength to shoes. Leather would be applied on the side of the foot, and rubber on the outsole. The study shows that family concerns could help elderly people to relive depression [33]. Based on this consideration and to ensure elderly safety if they fell, the function of auto alarm with sensory of falling, GPS, and RFID would be integrated within shoes. In that way, their children could be noticed by the phone at the first time if they fell.

The model safe footwear for elderly people to prevent falling would have a broad flat slip-resistant outsole, suitable cap cavity with proper material, foot arch support, and auto alarm of falling. Figure 3 shows the key features of the improved footwear design.

(a) Flared sole with non slip

(b) Wider toe cap cavity

(c) Insole with foot arch support

(d) Auto alarm function with GPS

Figure 3. Features of the improved footwear design for elderly people

CONCLUSIONS

The results from this study presented that there are at least 17 risk factors for elderly falls. Seven of them were identified as strong or moderate problems and could be mitigated by improving the shoes. The seven risk factors include shoes with non-skid resistance, stiff materials and narrow cavity of shoes, improper high heel, depressed mood, reduced muscle strength, and foot deformation. The design was focused on slip-resistant, wider toe cap, foot arch support, the flared sole and GPS integration. The improved functional shoes could be considered as an appropriate intervention for elderly falls issues.

However, further study is suggested to determine the effectiveness of elderly falls. A large size of sample is required to define the strong evidence of the effect, and a long-term validation is necessary to identify whether the fall rate is reduced by wearing the functional shoes.

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BIODEGRADABLE POLYMER COMPOSITE BASED ON NBR RUBBER AND PROTEIN WASTE

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BIODEGRADABLE POLYMER COMPOSITE BASED ON NBR RUBBER AND PROTEIN WASTE

ABSTRACT. The aim of this work is to characterize a biodegradable polymer composite based on butadiene-co-acrylonitrile rubber (NBR) and protein waste (ground leather). The biodegradable polymer composite was obtained by the mixing technique on a Brabender Plasti-Corder mixer and then on an electric roller (without heating), between its rollers, with sulfur vulcanization activators and Th accelerator, relative to 100 parts plasticized elastomer, obtaining 3-4 mm thick sheets, with strict observance of the technological recipe, but also of the established mode of operation. The obtained mixtures are then subjected to rheological characterization to determine the vulcanization time using the Monsanto rheometer (to determine the optimum temperature and vulcanization times in the laboratory electric press in specific molds for obtaining specimens to be subjected to subsequent characterization). Biodegradable polymeric composites based on butadiene-co-acrylonitrile rubber (NBR) and protein waste (leather waste from the footwear and leather goods industry) were made at optimal working parameters, and the characterization was performed on equipment specific to elastomers and according to standards in force for the footwear and consumer goods industry such as: plates for general purpose footwear soles as well as for water and mud environments, but also for the food industry, car mats, gaskets and components used under normal working conditions, technical plates, insoles, etc.

KEY WORDS: NBR rubber, protein waste, biodegradable, vulcanized, composite

COMPOZIT POIMERIC BIODEGRADABIL PE BAZĂ DE CAUCIUC NBR ȘI DEȘEU PROTEIC

REZUMAT. Scopul acestei lucrări este de a caracteriza un compozit polimer biodegradabil pe bază de cauciuc butadien-co-acrilonitril (NBR) și deșeuri proteice (piele măcinată). Compozitul polimeric biodegradabil a fost obținut prin tehnica amestecării pe un amestecător Brabender Plasti-Corder și apoi s-a completat pe un valț electric (fără încălzire), între rolele acestuia, cu activatori de vulcanizare sulf și accelerator Th, raportate la 100 părți elastomer plastifiat, obținându-se recepturi sub formă de foi de 3-4 mm grosime, cu respectarea strictă a rețetei tehnologice, dar și a modului de operare stabilit. Apoi amestecurile obținute sunt supuse caracterizării reologice pentru determinarea timpului de vulcanizare cu ajutorul reometrului Monsanto (pentru stabilirea temperaturii și timpilor de vulcanizare optimi în presa electrică de laborator în matrițe specifice pentru obținerea de epruvete ce vor fi supuse caracterizării ulterioare). Compozitele polimerice biodegradabile pe bază de cauciuc butadien-co-acrilonitric (NBR) si deșeu proteic (deșeu de piele provenit din industria de încălțăminte și marochinărie) au fost efectuate la parametrii de lucru optimi, iar caracterizarea s-a efectuat pe aparatura specifică elastomerilor și conform standardelor în vigoare pentru industria de încălțăminte și a bunurilor de larg consum precum: plăci pentru tălpi pentru uz general, apă și noroi, dar și pentru cele utilizate în industria alimentară, covoare auto, garnituri și repere utilizate în condiții normale de lucru, plăci tehnice, branțuri, etc.

CUVINTE CHEIE: cauciuc NBR, deșeuri proteice, biodegradabil, vulcanizat, compozit

COMPOSITE POLYMÈRE BIODÉGRADABLE À BASE DE CAOUTCHOUC NBR ET DE DÉCHETS PROTÉIQUES

RÉSUMÉ. Le but de ce travail est de caractériser un composite polymère biodégradable à base de caoutchouc butadiène-co-acrylonitrile (NBR) et de déchets protéiques (cuir broyé). Le composite polymère biodégradable a été obtenu par la technique de mélange sur un mélangeur Brabender Plasti-Corder puis sur un rouleau électrique (sans chauffage), entre ses rouleaux, avec des activateurs de vulcanisation au soufre et un accélérateur Th, pour 100 parties d'élastomère plastifié, obtenant de feuilles de 3 à 4 mm d'épaisseur, dans le strict respect de la recette technologique, mais aussi du mode de fonctionnement établi. Les mélanges obtenus sont ensuite soumis à une caractérisation rhéologique pour déterminer le temps de vulcanisation à l'aide du rhéomètre Monsanto (pour déterminer la température optimale et les temps de vulcanisation dans la presse électrique de laboratoire dans des moules spécifiques pour l'obtention d'échantillons à soumettre à une caractérisation ultérieure). Des composites polymères biodégradables à base de caoutchouc butadiène-co-acrylonitrile (NBR) et de déchets protéiques (déchets de cuir issus de l'industrie de la chaussure et de la maroquinerie) ont été réalisés à des paramètres de travail optimaux, et la caractérisation a été réalisée sur des équipements spécifiques aux élastomères et selon les normes en force pour l'industrie de la chaussure et des biens de consommation tels que : semelles à usage général, eau et boue, mais aussi pour celles utilisées dans l'industrie alimentaire, tapis de voiture, joints et pièces utilisés dans des conditions normales de travail, plaques techniques, semelles, etc.

MOTS CLÉS : caoutchouc NBR, déchets protéiques, biodégradable, vulcanisé, composite

INTRODUCTION

Waste designates a material emerging as a result of a biological or technological process that can no longer be used as such. The Romanian government has issued a series of government decisions regarding waste management, but the most important is G.D. no. 856/2002, which refers to "Introduction of waste management records and the European Waste Catalog". The European Commission adopted in December 2015 a package of measures on the circular economy to help European businesses and consumers make the transition to an economy

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in which resources are used sustainably [1, 2]. By using new and advanced technologies, but also by reusing and recycling waste, we can contribute to both environmental protection, protection of human health by eliminating toxins released during their incineration and increasing the turnover of economic agents globally [3, 4].

Recently, in the competition of polymer composites, new improvements appear in the synthesis of elastomers, in their processing in the presence of new materials, which when used can restore predetermined properties [5, 6]. Polymer composites based on elastomers have been intensively studied lately, especially in fields such as the automotive, electrical, household, gardening and plastic packaging of any type or shape. The structure of composite materials includes: elastomers, activators, anti-degradants, etc. [7-9]. After the vulcanization process elastomers keep their solid shape, but vulcanization influences the physical-mechanical characteristics such as elasticity, elongation at break, abrasion resistance, etc. [10, 11]. Thus, butadiene-co-acrylonitrile rubber (NBR)-based vulcanized elastomers have very good resistance to mineral oils, petroleum products, aging resistance, abrasion resistance and low gas permeability. The addition of vulcanization accelerators (Vulcacite Th - tetramethylthiuram disulfide) improves the physical-mechanical properties, and the antioxidants (IPPD - N-isopropyl-N'-phenyl-p-phenylenediamine) are introduced into the rubber mixture in order to prevent or reduce effects of time degradation of vulcanized elastomers (aging) under the action of various factors such as: oxygen, ozone, copper, manganese, iron, light, high temperature, repeated mechanical stress [12].

Biodegradable polymeric composites based on butadiene-co-acrylonitrile rubber (NBR) and protein waste (leather waste from the footwear and leather goods industry) were processed by mixing technique in a Brabender mixer, then on an electric roller provided with water cooling, then rheologically tested to determine the optimal vulcanization times for pressing in the electric press (in molds specific to elastomeric polymer composites) at controlled times, temperatures and pressures, to obtain products with characteristics necessary for use in the footwear and consumer goods industry such as: plates for general purpose footwear soles as well as for water and mud environments, but also for the food industry, car mats, gaskets and components used under normal working conditions, technical plates, insoles, etc. [13-15].

EXPERIMENTAL

Materials

Materials used to obtain the biodegradable composite based on butadiene-co-acrylonitrile and protein waste were: (1) butadiene-co-acrylonitrile rubber (NBR rubber): acrylonitrile content - 34%; Mooney viscosity (100%) - 32±3; density - 0.98 g/cm^3; (2) Stearin: white flakes; moisture - 0.5% max; ash – 0.025 % max; (3) zinc oxide microparticles (ZnO): white powder, precipitate 93-95%, density – 5.5 g/cm, specific surface – 45-55 m^2/g; (4) silicon dioxide (SiO_2): density: 1.9 - 4.29 g/cm^3, molar mass – 60.1 g/mol; (5) Kaolin: white powder, molecular weight 100.09; (6) protein waste: ground leather functionalized with potassium oleate; (7) protein waste - ground leather from the footwear and leather goods industry; (8) mineral oil; (9) N-isopropyl-N'-phenyl-p-phenylenediamine (IPPD 4010): density – 1.1 g/cm^3, solidification point over 76.5°C, flat granules coloured brown-dark purple) (10) Sulphur (S): vulcanization agent, fine yellow powder, insoluble in water, melting point: 115°C, faint odor; (11) tetramethylthiuram disulfide (Th): curing agent, density – 1.40g/cm^3, melting point <146°C, an ultrafast curing accelerator.

Methods

Preparation of Biodegradable Composite based on NBR Rubber and Protein Waste

Biodegradable polymer composites are made by blending on a Brabender mixer. After dosing each component according to the recipe, Table 1, by the mixing technique on a Brabender Plasti-Corder mixer with a capacity of 350 cm^3, establishing the initial working temperature of 36°C, the butadiene-co-acrylonitrile (NBR) rubber is introduced for plasticization for 1'30'', at 40 rpm, then the rest of the ingredients (without vulcanizing agents) are added: stearin plasticizer, active filler - ZnO microparticle, kaolin (mineral filler), ground waste, in proportion of 10, 20, 30 and 50% and functionalized with potassium oleate, mineral oil, IPPD antioxidant, strictly observing the order of introduction of ingredients, for 4’, at 20 rpm, continuing to mix until it is homogenized for 2’, at temperatures between 60-100°C, 80-100 rpm.

Before being added to the formulation, the leather waste was ground to a size of 0.35 mm using a cryogenic mill at a speed of 12000-14000 rpm and functionalized with a proportion of 20% potassium oleate at the temperature of 60°C. Then between the rollers of an electric roller without heating, the mixture is completed with sulfur vulcanization activators and Th accelerator, relative to 100 parts of plasticized elastomer, obtaining 3-4 mm thick sheets. Afterwards, the biodegradable polymeric composites are rheologically tested on a Monsanto Rheometer at 165°C for 24’ to determine the optimal vulcanization times by pressing in the electric press, from which 150x150x2 mm specimens will be obtained by pressing in molds specific to elastomeric polymer composites, by the method of compression between its plates, for the physical-mechanical, chemical and morpho-structural tests. The optimal parameters for obtaining test specimens by pressing in the electric press are: pressing temperature - 165°C; pressing time - 5 minutes; cooling time - 10 minutes (water cooling); pressure - 300 kN. The test pieces obtained are left for 24 hours at ambient temperature, then subjected to the corresponding characterizations according to the standards in force: normal state and accelerated aging at 70°C and 168 hours.

Table 1: Formulation of biodegradable polymer composite based on butadiene-co-acrylonitrile rubber (NBR) compounded with protein waste (ground leather)

Symbol	MU [g]	BO (control)	$BCPP_0$	$BCPP_1$	$BCPP_2$	$BCPP_3$	$BCPP_4$
Butadiene-co-acrylonitrile (NBR)	g	150	150	150	150	150	150
Stearin (flakes)	g	1.8	1.8	1.8	1.8	1.8	1.8
Zinc oxide (ZnO - active powder)	g	7.5	7.5	7.5	7.5	7.5	7.5
Silicon dioxide (SiO_2)	g	45	-	30	20	-	-
Kaolin	g	37.5	37.5	37.5	37.5	37.5	37.5
Functionalized leather waste with potassium oleate	g	-	-	15	30	45	75
Non-functionalized leather waste	g	-	45	-	-	-	-
Mineral oil	g	15	15	15	15	15	15
IPPD 4010	g	4.5	4.5	4.5	4.5	4.5	4.5
Sulfur (S)	g	2.25	2.25	2.25	2.25	2.25	2.25
Tetramethylthiuram disulfide (Th)	g	0.9	1.5	0.9	1.5	0.9	0.9

RESULTS AND DISCUSSIONS

Characterization of Brabender Processing Diagrams

According to the registered Brabender diagrams, Figure 1, it can be observed that for the mixtures obtained by the mixing technique on the Brabender Plasti-Corder, the working method presented above is observed (when preparing the polymer composites). Thus, in the first portion (A-B) which lasts 1’30” at 40 rpm, the elastomer, butadiene-co-acrylonitrile rubber is introduced into the mixer and therefore the torque increases. The first loading peak, A, corresponds to adding the rubber. As the torque increases, so does the temperature due to the friction of the mixer screws. The torque begins to decrease near A to B, mainly due to the homogenization and plasticization of the butadiene-co-acrylonitrile rubber, as well as due to the increase in temperature from shearing. Then the other ingredients are introduced and the rotation speed is reduced to 20 rpm for 4’, keeping the mixer open (until all the ingredients are incorporated according to the recipe). Between point B and point X, the torque begins to increase due to the incorporation of the ingredients, but also as a result of the compaction and reinforcement of the elastomer. After incorporating the fillers and other ingredients, the second loading peak, X, is observed when a maximum torque point appears. The torque begins to decrease, indicating the homogenization of the mixture. Afterwards, the compound is homogenized for 2’ at 80 rpm, during which time the mixer is kept closed, obtaining a maximum value of the torque due to the compaction and homogenization of the rubber mixture. This is generally followed by a decrease in the torque value, which indicates both the homogenization of the mixture and the increase in the temperature of the mixture due to friction at a higher rotational speed with the mixer closed, Table 2.

Table 2: Characteristics presented in Brabender processing diagrams for butadiene-co-acrylonitrile rubber (NBR) compounded with protein waste

Characteristics	BO (control)	$BCPP_0$	$BCPP_1$	$BCPP_2$	$BCPP_3$	$BCPP_4$
Temperature at peak load, °C	70	86	63	73	95	59
Inflection point temperature, °C	94	118	92	97	118	84
Maximum temperature, °C	106	118	109	109	120	90
Energy at peak load, kNm	138.8	104.0	15.9	138.7	69.7	12.6
Maximum energy, kNm	138.7	139.1	133.7	122.3	154.9	242.2
Gelling zone energy, kNm	30.2	4.0	48.7	40.3	0.4	3.3
Specific energy, kNm/g	1.3	0.9	1.3	1.2	0.8	1.0
Gelling rate, Nm/min	-28.0	-3.6	240.5	47.6	114.0	-516.3

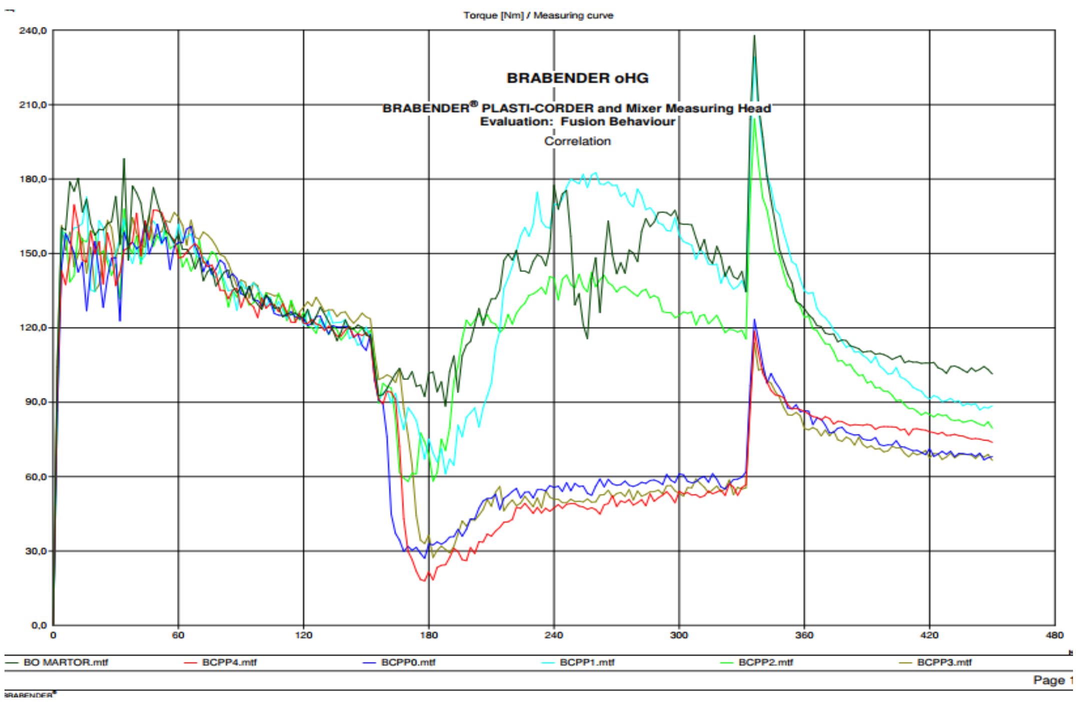


Figure 1. Variation of the torque with time recorded on the Brabender Plasti-Corder when obtaining polymeric composites based on NBR rubber compounded with leather waste functionalized with potassium oleate

Rheological Characterization of Biodegradable Polymer Composites

Biodegradable polymeric composites are rheologically tested on a Monsanto Rheometer at 165°C for 24'. Following the rheological test, the optimal vulcanization times in the press are established in order to obtain the specimens that will be subjected to the physical-mechanical test.

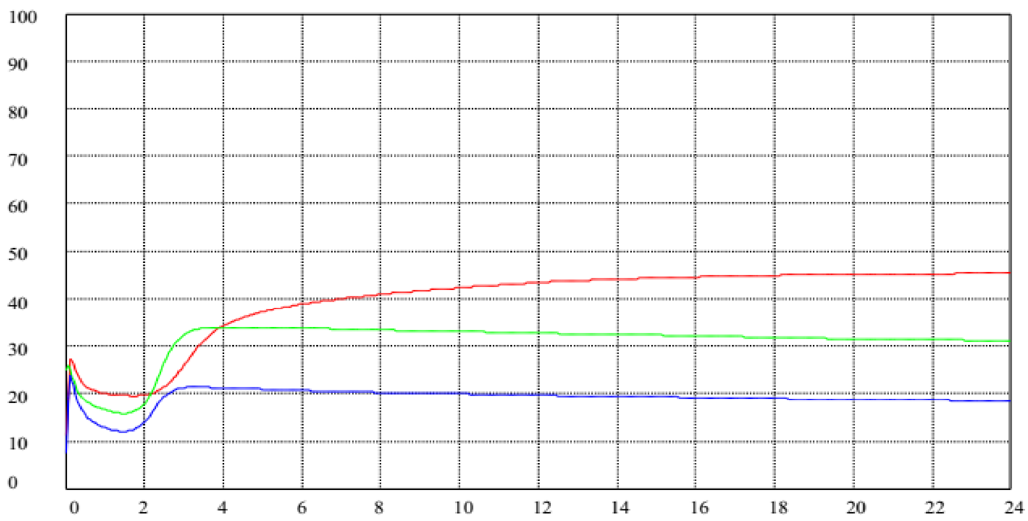
Rheological characteristics of mixtures based on NBR rubber compounded with leather waste (non-functionalized and functionalized with potassium oleate) are shown in Table 3.

Table 3: Rheological characteristics of mixtures based on NBR rubber compounded with leather waste

Rheological characteristics at 165°C	BO (control)	$BCPP_0$	$BCPP_1$	$BCPP_2$	$BCPP_3$	$BCPP_4$
ML (dNm)	17.3	12.8	19.5	18.4	15.7	11.9
MH (dNm)	46.9	29.3	45.3	43.1	33.8	21.4
ΔM = MH-ML (dNm)	29.6	16.5	25.8	24.7	18.1	9.5
t_{s2} (min)	2.91	2.3	2.48	2.67	1.95	1.98
t_{50} (min)	6.38	2.72	3.66	3.58	2.38	2.22
t_{90} (min)	18.61	3.47	10.79	5.18	2.88	2.64

From the rheological analysis made by comparing the samples, Figure 2, it is observed that by replacing the amount of silicon dioxide active filler with functionalized/non-functionalized leather waste powder, the rheological characteristics of the mixtures are modified as follows:

- the minimum torque (ML) as well as the maximum torque (MH) decrease as the amount of leather waste powder functionalized with potassium oleate increases;
- the variation of the torque (ΔM = MH-ML) decreases as the amount of leather waste powder functionalized with potassium oleate increases, to the detriment of the amount of silicon dioxide; this indicates a stiffness of the mixtures in the unvulcanized state which may be due to the agglomeration of the leather waste powder or its larger size compared to the size of the silicon dioxide particles;
- for all the samples the reversal phenomenon is observed, which is specific to the vulcanized mixtures with sulfur and vulcanization accelerators (Figure 1), indicating a degradation of the mixtures at high temperatures by loosening some crosslinking bonds;
- the scorching time (t_{s2}) has very good values, over 1.9', and the optimal vulcanization time (t_{90}) decreases with the replacement of the active filler of silicon dioxide with the filler of functionalized / non-functionalized leather waste powder.



Physical-Mechanical Characterization of Biodegradable Polymeric Composites

Physical-mechanical characterization of normal state and accelerated aging at 70°C and 168 hours was performed according to the standards in force by the following methods: hardness; elasticity, tensile strength. Table 4 shows the values of the physical-mechanical characteristics obtained.

Table 4: Physical-mechanical characterization of biodegradable polymer composites based on NBR rubber compounded with leather waste non-functionalized/functionalized with potassium oleate

Sample	BO (control)	$BCPP_0$	$BCPP_1$	$BCPP_2$	$BCPP_3$	$BCPP_4$
Physical-mechanical characteristics: Normal State						
Hardness, °Sh A	61	70	66	69	71	73
Elasticity, %	18	18	21	20	19	18
Tensile strength, N/mm^2	11.3	3.44	9.4	8.1	3.97	1.7
Physical-mechanical characterization: Accelerated aging at 70°C and 168 h						
Hardness, °Sh A	66	73	69	72	75	75
Elasticity, %	24	22	26	24	23	22
Tensile strength, N/mm^2	14.47	3.30	9.31	6.96	2.98	1.49

From the physical-mechanical analysis performed, Table 4, the following can be seen:

- The hardness of biodegradable polymer based on NBR rubber compounded with leather waste non-functionalized/functionalized with potassium oleate increases with the amount of leather waste added in the mixture with maximum 12°Sh A;
- Elasticity decreases in proportion to the percentage of leather waste functionalized with potassium oleate introduced into the mixture;
- The values of tensile strength decrease as the active filler of silicon dioxide is replaced by the leather waste, and has values between 1.7-9.4 N/mm^2;
- After accelerated aging for 168 h at 70°C there are increases in hardness and elasticity for all samples, while tensile strength decreases significantly, due to the replacement of the active filler with leather waste functionalized with potassium oleate.

CONCLUSIONS

The paper presents the rheological, physical-mechanical Brabender Plasti-Corder mixer diagrams characterization of biodegradable polymeric composites based on elastomer, butadiene-co-acrylonitrile rubber, compounded with leather waste (from the footwear and leather goods industry, ground using a cryogenic mill at a speed of 12000-14000 rpm, in the form of leather powder at a size of 0.35 mm) non-functionalized/functionalized with potassium oleate in a proportion of 20% at 60°C, vulcanization activator - sulfur, Th accelerator and elastomer-specific ingredients. The characterization was performed using the equipment specific to elastomers and according to the standards in force.

Following the characterization performed, it can be seen that the mixtures were made according to the working recipes at the optimum parameters and working times, and from the physical-mechanical characterization performed, the polymer composites based on butadiene-co-acrylonitrile elastomer and leather waste (non-functionalized/functionalized with potassium oleate) it results that they have optimal values that meet the standards and have potential applications for general purpose footwear and in the industry of elastomeric components without special characteristics.

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TECHNOLOGY DEVELOPMENT OF LIQUID FINISHING OF CHROME-TANNED GOATSKIN

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TECHNOLOGY DEVELOPMENT OF LIQUID FINISHING OF CHROME-TANNED GOATSKIN

ABSTRACT. There has been developed resource-saving environmentally friendly technology for producing chrome-tanned goatskin for shoe upper using new synthetic materials, which involves neutralization in the presence of Politan BN – syntan-neutralizer based on naphthalene sulfonic acid (Codyeco S.p.a., Italy) in the amount of 3.6% (in terms of dry residue), fatliquoring with a mixture of drugs Sulphirol C – a fatliquoring drug based on sulfonated fish oil, resistant to electrolytes (Smit & Zoon, Netherlands) and SMX 473 – a semi-synthetic composition based on sulfonated and sulphated fats (Shebekinsky industrial chemistry, Russia) in the ratio of 70:30 with a total fat consumption of 5.0% (in terms of 100% fat), retanning-filling Retanal LMV 100 – retanning agent based on melamine (Cromogenia Units, Spain) in the amount of 4.5% (in terms of dry residue). This allows to expand the range of chemical materials for liquid finishing and increase production efficiency (conditional economic benefit is UAH 9.22 per 1 m^2 of finished products due to more rational use of raw and material resources), while increasing the uniformity of distribution of tensile strength in different areas of the skin, strength of surface, elongation at strain 10 MPa in 1.2-1.4 times, the skin yield by area increases by 1.8%, and its grade – by 0.7%; improve the physical, mechanical and hygienic properties of the skin; reduce the harmful load on the environment. The technology has passed production tests at PJSC “Chinbar” (Kyiv, Ukraine) and is ready for implementation at tanneries.

KEY WORDS: resource-saving technology, liquid finishing, leather for shoe upper

DEZVOLTAREA TEHNOLOGICĂ A UNUI FINISAJ LICHID PENTRU PIEI DE CAPRĂ TĂBĂCITE ÎN CROM

REZUMAT. S-a dezvoltat o tehnologie ecologică, cu economie de resurse, pentru fabricarea pielii de capră tăbăcită în crom pentru fețe de încălțăminte folosind materiale sintetice noi, care presupun neutralizarea în prezența Politan BN – sintan neutralizator pe bază de acid naftalen sulfonic (Codyeco S.p.a., Italia) în cantitate de 3,6% (reziduu uscat), ungere cu un amestec de Sulphirol C – un agent de ungere pe bază de ulei de pește sulfonat, rezistent la electroliți (Smit & Zoon, Olanda) și SMX 473 – o compoziție semi-sintetică pe bază de grăsimi sulfonate și sulfatate (Shebekinsky industrial chemistry, Rusia) în raport de 70:30 cu un consum total de grăsimi de 5,0% (raportat la 100% grăsime), agent de retăbăcire-umplere Retanal LMV 100 – agent de retăbăcire pe bază de melamină (Cromogenia Units, Spania) în cantitate de 4,5% (reziduu uscat). Acest lucru permite extinderea gamei de materiale chimice pentru finisaj lichid și creșterea eficienței producției (beneficiul economic condiționat este de 9,22 UAH pe 1 m^2 de produs finit datorită utilizării mai raționale a resurselor prime și materiale), crescând în același timp uniformitatea distribuției rezistenței la tracțiune în diferite zone ale pielii, tensionare la apariția fisurilor pe stratul exterior, alungire la deformare de 10 MPa de 1,2-1,4 ori, suprafața utilă a pielii crește cu 1,8%, iar calitatea sa – cu 0,7%; îmbunătățirea proprietăților fizice, mecanice și igienice ale pielii; reducerea poluării asupra mediului. Tehnologia a trecut testele de producție la PJSC „Chinbar” (Kiev, Ucraina) și este gata de implementare în tăbăcării.

CUVINTE CHEIE: tehnologie de economisire a resurselor, finisaj lichid, piele pentru fețe încălțăminte

DÉVELOPPEMENT TECHNOLOGIQUE D’UNE FINITION LIQUIDE POUR CUIR DE CHÈVRE TANNÉ AU CHROME

RÉSUMÉ. Une technologie respectueuse de l’environnement et économe en ressources a été développée pour la fabrication de la peau de chèvre tannée au chrome pour les tiges de chaussures en utilisant de nouveaux matériaux synthétiques, ce qui implique la neutralisation en présence de Politan BN - neutraliseur de syntan à base d’acide naphtalène sulfonique (Codyeco Spa, Italie) en quantité de 3,6% (en termes de résidus secs), graissage avec un mélange de Sulphirol C – un agent de graissage à base d’huile de poisson sulfonée, résistant aux électrolytes (Smit & Zoon, Pays-Bas) et SMX 473 – une composition semi-synthétique à base de graisses sulfonées et sulfatées (Shebekinsky industrial chemistry, Russie) dans le rapport 70:30 avec une consommation totale de graisse de 5,0% (en termes de 100% de graisse), retannage-remplissage Retanal LMV 100 – agent de retannage à base de mélamine (Cromogenia Units, Espagne) à hauteur de 4,5% (en termes de résidus secs). Cela permet d’élargir la gamme de matériaux chimiques pour la finition liquide et d’augmenter l’efficacité de la production (l’avantage économique conditionnel est de 9,22 UAH pour 1 m^2 de produits finis en raison d’une utilisation plus rationnelle des ressources brutes et matérielles), tout en augmentant l’uniformité de la répartition de la résistance à la traction dans différentes zones de la peau, déformation lors de l’apparition de fissures dans la couche externe, allongement lors de la déformation de 10 MPa 1,2-1,4 fois, la surface utile de la peau augmente de 1,8 % et sa qualité – de 0,7%; améliorer les propriétés physiques, mécaniques et hygiéniques de la peau; réduire la pollution de l’environnement. La technologie a passé les tests de production chez PJSC « Chinbar » (Kiev, Ukraine) et est prête à être mise en œuvre dans les tanneries.

MOTS CLÉS : technologie d’économie de ressources, finition liquide, cuir pour tige de chaussure

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INTRODUCTION

One of the common types of hides is goatskin, which has a fairly dense and strong dermis, and the leather made of it is soft and elastic, has a beautiful pattern of the surface grain (pattern) [1]. This determines the attractiveness of such leather as a material for manufacturing high quality model shoes, clothes, haberdashery, etc. That is why recently, in the competition for markets, foreign producers of soft, elastic leather goods from goatskin are increasingly entering the Ukrainian market, thus displacing the domestic producer. Therefore, the current problem is the creation of goatskin production technology with improved physical, mechanical and hygienic properties to meet the functional and operational requirements for footwear, and given the realities of the current state of the economy and ecology, – strengthening the resource-saving and environmental imperative of new development.

Skinners have known for a long time about the impact of dyeing-fatliquoring processes on the physical and mechanical, hygienic and other properties of the skin, the purpose of which is to further form the structure of the dermis after tanning. The composition and sequence of the individual stages of liquid finishing are different and depend on the type and purpose of the skin. The processes of retanning, filling, fatliquoring are precisely the processes that, after treatment with tannins, change the characteristics of leather products most significantly [2, 3].

Advanced reagents for retanning-filling are polymeric compounds obtained on the basis of acrylic and maleic acids [4-10], syntans with low formaldehyde content [11-19], as well as products of industrial waste modification [20, 21]. Improving the fatliquoring involves the use of more effective substances of both synthetic and natural origin individually and in the form of compositions (mixtures) [22-27], or in general with a change in the technological scheme, for example, by applying thermostable enzymes before fatliquoring [28].

According to the analysis of the literature and practical experience of enterprises in the industry, it has been established that the most part of all research to improve existing or develop innovative technologies is based on the search for and introduction of new modern chemical materials. At the same time, the effectiveness of the study is most clearly manifested at the stage of liquid finishing, during which there is an additional formation of the dermis structure and adding the desired properties to the skin. Based on the above, the purpose of this study has been formulated to develop resource-saving and environmentally friendly technology for liquid finishing of chrome-tanned goatskin.

EXPERIMENTAL

Materials and Methods

The study uses a semi-finished product from goatskin, as well as chemical materials common in leather production as a means for liquid finishing of the skin: Sulphirol C – a fatliquoring material based on sulfonated fish oil, resistant to electrolytes (Smit & Zoon, Netherlands); SMX 473 – semi-synthetic composition based on sulfonated and sulphated fats (Shebekinsky industrial chemistry, Russia); Politan BN – syntan-neutralizer based on naphthalene sulfonic acid (Codyeco S.p.a., Italy); Retanal LMV 100 – a melamine-based retanning agent (Cromogenia Units, Spain).

Microscopical Method

The impact of liquid finishing on the change of the supramolecular structure of the dermis collagen and the way of sedimentation of the chrome tanning agent in the supramolecular structure have been studied with the help of scanning electronic microscopy (SEM) using the device JSM-6490-LV, GEOL (Japan) and applying microprobe analyses based on energy- and wave dispersion spectrometers (EDS + WDS, OXFORD, UK) [29].

Methods of Studying the Skin Properties

Physical and mechanical trial runs and the chemical analysis of the leather have been done using the official IULTCS methods: sampling location (ISO 2417:2016), sample preparation and conditioning (ISO 2419:2012), shrinkage temperature (ISO 3380:2015), strength of surface (ISO 3379:2015), strength and percentage extension (ISO 3376:2011), apparent density (ISO 2420:2002), measurement of thickness (ISO 2589:2016), measurement of area (ISO

11646:2014), determination of tear load (ISO 3377-1:2011), water vapour permeability (ISO 14268:2012).

The margin of error of the test when studying physical and mechanical properties was at most 5 %, the one of chemical composition indices was at most 3%.

RESULTS AND DISCUSSIONS

The results of previous studies [29-34] have become the basis for developing technology for producing chrome-tanned goatskin for shoe upper by using selected synthetic and fatliquoring materials during liquid finishing. Technological parameters and sequence of physical and chemical processes are given below:

1. *Washing*: float ratio (FR) 1.5, temperature 30-35°C, duration 0.5 h;

2. *Neutralization*: FR 1.0, temperature 32-35°C, duration 1.0-1.5 h, consumption Politan BN 3.6% (in terms of dry residue). The end of the process is determined by the pH of the spent solution indicator bromocresol green;

3. *Washing*: FR 1.5, temperature 30°C, duration 0.5 h;

4. *Washing*: FR 1.5, temperature 30°C, non-ionic surfactant (e.g. Savenol NWP) 0.2%, duration 0.5 h;

5. *Dyeing*: FR 1.0, temperature 32-35°C, duration 2.0 h, consumption of dye diluted with water in a ratio of 1:10, 4.0%. After complete absorption of the dye, dilute (1:10) formic acid in the amount of 1.0% is added to the solution, the treatment is continued for another 30 minutes;

6. *Washing*: FR 1.5, temperature 50-55°C, duration 15 min;

7. *Fatliquoring*: FR 1.0, temperature 50-55°C, duration 1.0 h; a mixture of drugs Sulphirol C and SMX 473 in a ratio of 70:30 with a total fat consumption of 5.0% (in terms of 100% fat);

8. *Washing*: FR 1.5, temperature 35-40°C, duration 15 min;

9. *Retanning-filling*: FR 1.0, temperature 35-40°C, duration 1.0 h, Retanal LMV 100 4.5% (in terms of dry residue);

10. *Washing*: FR 1.5, temperature 35-40°C, duration 15 minutes.

The consumption of all materials is calculated from the shaved weight considering the activity (or dry residue) of the reagents used.

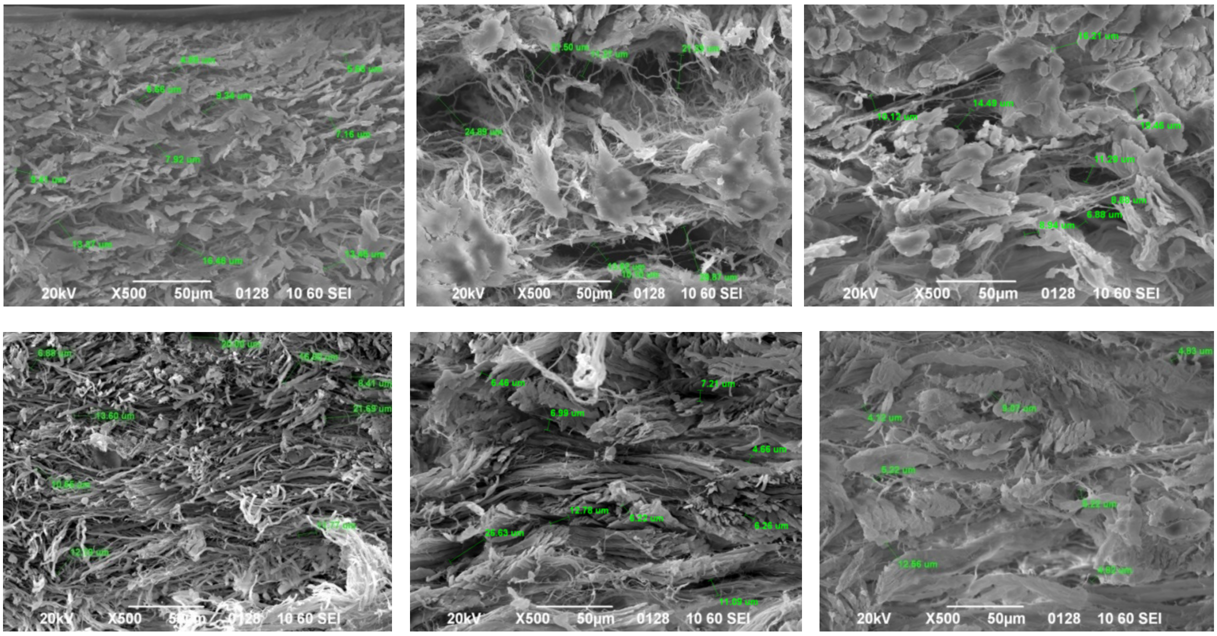
All previous and subsequent processes and operations are performed according to the known method of producing chrome-tanned goatskin for shoe upper [35].

The effectiveness of the new technology has been evaluated on the basis of analysis of photographs of microscopic sections, chemical composition and physical and mechanical tests of chrome-tanned leather from goatskin. For comparison, skin samples were used that were treated in the same sequence, but the neutralization process was performed with 0.6% carbonate and 1.5% sodium formate, the fatliquoring – using only the composition SMX 473 (consumption 5.0%), retanning-filling – Quebracho tannins (consumption of 4.5% by weight of samples).

After drying and moistening processes and operations, the final finishing of the skin was carried out by double coating of the following composition, wt. p. (consumption 70 ± 10 g/m^2): Codyeco RPI 4377 (18%) – 150; Acrylic 1755 (28.6%) – 100; casein (10%) – 50; wax emulsion (20%) – 40; water – 200. To fix the coating the composition was used, wt. p. (consumption 55 ± 10 g/m^2): nitro emulsion LE 5555 (80%) – 100; water – 100.

There were no complications during the treatment of the experimental group. According to organoleptic evaluation, the semi-finished product and finished leather had a pleasant neck and a clean, silky surface grain.

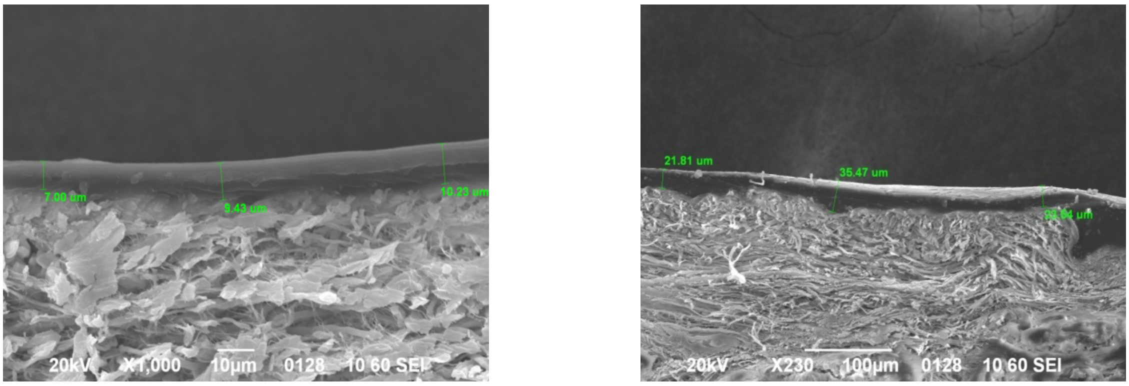
For microscopic examination and electron probe analysis, sections of skin samples were used, which were first dried with an alcohol-ether mixture, then, to provide electrical conductivity, they were coated with gold. As a result of the performed manipulations, microphotographs (Figure 1) were obtained, as well as spectrograms of the content and distribution of chromium compounds in the structure of the dermis (Figure 2).



b

Figure 1. Micrographs of the cross-section of the skins of the experimental (a) and control (b) groups (x 500)

From the obtained microphotographs (Figure 1) we can conclude that in skin samples there are morphological changes in the structure due to the nature of its formation, which is manifested in a more uniform, "layered" arrangement of individual structural elements, increasing the average distance between individual elements (L_{aver}) of experimental samples manufactured using the new technology (12.92 ± 6.24 µm) compared to the control ones (10.21 ± 5.72 µm).

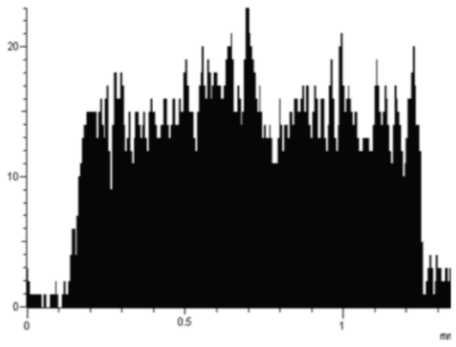


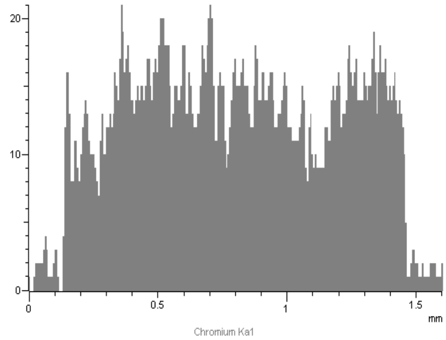
a b

Figure 2. Determination of coating thickness on skin microsections of the experimental (a) and control (b) groups (x 1000, x 230)

After measuring the thickness of the coating on micro cuts of the skin (Figure 2) a significant improvement of this indicator was found in the experimental group compared with the control group, because the average thickness of the coating (T_{aver}) on the experimental samples averages out 8.89 ± 1.37 µm, which 3,03 times less than the control indicator (26.94 ± 6.07 µm).

According to the results of electron probe analysis, it has been found out that in the experimental group, chromium tanning agent is distributed in the dermis, especially in its middle layers, more evenly than in the control group (Figure 3).





a b

Figure 3. WDS-analysis of the cross-section of the skins of the experimental (a) and control (b) groups

All of the above should increase the strength, elastic-plastic and hygienic properties of the skin, the quality of the coating on it, which is confirmed by the results of chemical analysis and physical and mechanical tests of the samples (Table 1).

To confirm the results of the laboratory tests, the new technology was tested in the production conditions of Kyiv leather enterprise PJSC "Chinbar" on a shaved semi-finished product Wet Blue, obtained by the current technology of production of chrome-tanned goatskin for shoe upper.

The weight of the experimental and control batches in the raw material was 400 kg. To obtain objective data, the method of alternating halves was used [36].

Table 1: Indicators of chrome-tanned goatskin for shoe upper (laboratory tests)

Index	Experimental group	Control group
Mass content, % (per completely dry substance), % – chromium oxide	4.6	4.4
– minerals	11.0	11.5
– substances, extracted with organic solvents	8.0	7.4
Tensile strength, MPa, σ_t	1.93	1.80
Strength of surface, MPa, σ_s	1.80	1.60
$\Delta\sigma = \sigma_t - \sigma_s$, MPa	0.13	0.20
Elongation at strain 10 MPa, %	30.0	25.0
Elongation at fracture, %	76.0	79.0
Distribution efficiency of tensile strength	0.82	0.46
Distribution efficiency of strength of surface	0.84	0.53
Distribution efficiency of percentage extension at 10 MPa	0.96	0.75
Distribution efficiency of elongation at fracture	0.87	0.85
Water vapour permeability, mg/sm^2 · h	2.11	1.89
Porosity, %	57.5	54.0
Yield on the thickness, %	92.0	90.8
Yield on the area, %	93.1	92.1
Volume yield, sm^3/100 g of protein	322.5	274.6
Shrinkage temperature, **°C**	105.5	104.0
Absorption drop of water, h	2.0	1.9
pH potassium chloride extract	4.7	4.3
Coating resistance to multiple bending, points	3.0	3.0
Coating resistance to wet friction, rotations	130.0	115.0
Adhesion of coating to the subsurface, H/m: – dry	450.0	430.0
– wet	110.0	100.0
Thickness of cover, g/mm^2	0.25	0.29

The semi-finished product of the experimental batch was processed according to the new technology, following the scheme: washing - neutralization - washing 1, 2 - dyeing - washing - fatliquoring - washing - retanning-filling - washing.

The semi-finished product of the control batch was neutralized with sodium carbonate and formate at a consumption of 0.6 and 1.5%, respectively, and fatliquoring was performed only with the drug SMX 473 at a consumption of 5.0%; retanning-filling was performed with Quebracho tannins in the amount of 4.5%.

The consumption of all materials was determined from the shaved weight. All subsequent processes and operations were performed according to the current technology.

As before, during laboratory tests, no complications occurred during the processing of the experimental batch. According to organoleptic evaluation, the semi-finished product and finished leather had a pleasant neck and a clean, silky surface grain. In addition, the tested skins not only met the requirements of regulatory documentation, but also improved physical, mechanical and hygienic properties compared to skins made by the current technology (Table 2). Thus, the content of minerals in the experimental skins is less by 3.5%, and substances extracted with organic solvents, on the contrary, more by 13.2%. The tensile strength during stretching increases by 4.5%, and the strain during the appearance of cracks in the front layer by 8.4%. Reducing the difference between the strength of the skin as a whole and the strength of its outer layer indicates a more uniform distribution of chemical reagents in the structure of the dermis, which has a positive effect on the elastic-plastic and hygienic properties, the area received. The use of new chemical materials at the stage of liquid finishing has a positive effect on the quality of the coating on the skin, the thickness of the coating film.

The advantages of the new technology are also revealed in reducing the fat content in the spent solution by 5.6%, improving the ratio of biological oxygen demand (BOD) and chemical oxygen demand (COD) to 71.4%, which will help green production, increase the likelihood of cleaning industrial effluents by biological methods.

The conditional economic benefit from introducing a new technology of liquid finishing of chrome-tanned leather from goatskin for the shoe upper will be equal to UAH 9.22 per 1 m^2 of finished products due to more rational use of raw and material resources, while the yield of leather by area increases by 1.8%, and its grade – by 0.7%.

Table 2: Comparative evaluation of new and current technologies for producing chrome-tanned goatskin for shoe upper (production tests)

Index	New technology	Current technology	DSTU 2726-94
Leather:			
Mass content, % (per completely dry substance), %			
– chromium oxide	4.5	4.2	no less 3.5
– minerals	10.9	11.3	–
– substances, extracted with organic solvents	8.3	7.2	3.7-10.0
Tensile strength, MPa	1.99	1.90	no less 1.80
Strength of surface, MPa	1.91	1.75	no less 1.50
Elongation at strain 10 MPa, %	32.0	27.0	15-35
Distribution efficiency of tensile strength	0.80	0.59	–
Distribution efficiency of strength of surface	0.81	0.63	–
Distribution efficiency of elongation at strain 10 MPa	0.90	0.72	–
Water vapour permeability, mg/sm^2 · h	2.15	1.90	–
Yield on the thickness, %	91.5	89.7	–
Yield on the area, %	92.6	90.8	–
Coating resistance to multiple bending, points	4	3	no less 3
Coating resistance to wet friction, rotations	140	120	no less 100
Adhesion of coating to the dry/wet subsurface, H/m:	460/115	445/110	–
Grade, %	90.6	89.9	–
Waste solution after liquid finishing:			
Fat content, mg/dm^3	236.0	250.0	–
CSAA content, mg/dm^3	117.0	125.0	–
Biochemical oxygen demand / Chemical oxygen demand, %	71.4	68.3	–

CONCLUSIONS

Resource-saving environmentally friendly technology has been developed for producing chrome-tanned goatskin for shoe upper using new synthetic materials, which involves neutralization in the presence of Politan BN – syntan-neutralizer based on naphthalene sulfonic acid (Codyeco S.p.a., Italy) in the amount of 3.6% in terms of dry residue), fatliquoring with a mixture of drugs Sulphirol C – fatliquoring drug based on sulfonated fish oil, resistant to electrolytes (Smit & Zoon, Netherlands) and SMX 473 – semi-synthetic composition based on sulfonated and sulphated fats (Shebekinsky industrial chemistry, Russia) in the ratio of 70:30 with a total fat consumption of 5.0% (in terms of 100% fat), retanning-filling Retanal LMV 100 – retanning agent based on melamine (Cromogenia Units, Spain) in the amount of 4.5% (in terms of dry residue).

According to the results of laboratory studies using scanning electronic microscopy (SEM), electron probe and other methods of instrumental and chemical analysis, it was found that in comparison with the current technology, the new technology provides more efficient use of raw and material resources due to more orderly arrangement of chemical materials in the dermis forming strong and at the same time flexible bonds. This is confirmed by the results of production testing in the terms of Kyiv leather enterprise PJSC "Chinbar", which established the following advantages of the new technology:

- reduction of mineral content in the skin by 3.5%, which will prevent the formation of salt spots during its operation in adverse climatic conditions in the form of precipitation;
- increase in the content of unbound fatty substances in the skin by 13.2%, which improves its elastic-plastic properties (elongation at strain 10 MPa increases by 15.6%) and the composition of wastewater (fat content in the spent solution decreases by 5.6%);
- increase of the strength of the skin as a whole by 4.5%, and its outer layer by 8.4%;
- improvement of hygienic properties (vapour permeability increases by 11.6%);
- reduction of the anisotropy of the main indicators of physical and mechanical properties (increasing the uniformity of distribution in different directions of the skin of tensile strength during tension, strain during cracking of the outer layer, elongation at strain 10 MPa in 1.2-1.4 times), that will cause more rational use of skin during cutting on details of footwear;
- increase in yield in thickness and area by 1.8%, respectively;
- improvement of the quality of the skin coating (indicators of resistance of the coating to repeated bending and wet friction, the adhesion of the coating film to the skin increases by 1.3, 1.2 and 1.1 times, respectively), which will also positively affect the consumer properties of leather products;
- improvement of the wastewater composition – in addition to the already mentioned reduction of fat content in the spent solution, the ratio of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) increases to 71.4%, which will help green production, increase the likelihood of industrial wastewater treatment.

In case of introduction of new resource-saving technology into production, the expected economic benefit will be UAH 9.22. per 1 m^2 of finished products due to a more rational use of raw and material resources, while the skin yield by area will increase by 1.8%, and grade – by 0.7%.

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OPTIMIZATION OF VALUES OF TECHNOLOGICAL PARAMETERS FOR OBTAINING THERMOPLASTIC POLYMER COMPOSITION FOR BOTTOM SHOES

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OPTIMIZATION OF VALUES OF TECHNOLOGICAL PARAMETERS FOR OBTAINING THERMOPLASTIC POLYMER COMPOSITION FOR BOTTOM SHOES

ABSTRACT. This work reveals the dependence of the composition and production parameters on the properties of a thermoplastic polymer composition based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride (EVA / PVC-S), as well as the choice of the optimal composition of the mixture and finding the optimal technological parameters for its production. Thermoplastic polymer-sole compositions were obtained by the method of thermomechanical mixing. To describe the properties of polymer - plantar compositions, depending on the ratio of components and technological parameters of obtaining, the method of mathematical planning – "Full factorial experiment" of type № = 2^k was chosen, which allows to obtain separate estimates of linear effects and two-, three-factor interactions. In this work, to build a mathematical model, the following factors were selected: the content of EVA in the composition, the temperature and mixing rate, and regression equations were used when obtaining a new type of shoe bottom material using a full factorial experimental method. Optimal results were obtained when the EVA content of the polymer composition was 15%, the mixing temperature was 185°C, and the mixing speed was 25 rpm. The strength and operational-technological indicators of the quality of a thermoplastic polymer composition for the bottom of footwear based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride have been determined. Regression equations for the dependence of the deformation-strength properties on the technological factors of the creation of polymer sole compositions are constructed. It has been proved that by selecting the optimal values of technological parameters it is possible to obtain a sole material with high deformation-strength and operational-technological characteristics.

KEYWORDS: copolymer of ethylene with vinyl acetate, suspension polyvinyl chloride, mathematical planning of the experiment, generalized quality indicator, desirability function.

OPTIMIZAREA VALORILOR PARAMETRILOR TEHNOLOGICI ÎN VEDEREA OBȚINERII UNUI COMPOZIT POLIMERIC TERMOPLASTIC PENTRU TĂLPI DE ÎNCĂLȚĂMINTE

REZUMAT. Această lucrare scoate în evidență dependența compoziției și a parametrilor de producție de proprietățile unui compozit polimeric termoplastic pe bază de copolimer de etilenă-acetat de vinil și clorură de polivinil în suspensie (EVA / PVC-S), precum și alegerea compoziției optime a amestecului și găsirea parametrilor tehnologici optimi pentru producerea acestuia. Compozitele polimerice termoplastice pentru tălpi au fost obținute prin metoda amestecării termomecanice. Pentru a descrie proprietățile compozitelor polimerice, în funcție de raportul dintre componente și parametrii tehnologici de obținere, s-a ales metoda de planificare matematică – „Experiment factorial complet" de tip № = 2^k, care permite obținerea unor estimări separate ale efectelor liniare și interacțiuni cu doi sau trei factori. În această lucrare, pentru a construi un model matematic, au fost selectați următorii factori: conținutul de EVA în compoziție, temperatura și viteza de amestecare, precum și utilizarea ecuațiilor de regresie la obținerea unui nou tip de material pentru tălpi de încălțăminte folosind un plan experimental factorial complet. S-au obținut rezultate optime atunci când conținutul de EVA al compoziției polimerice a fost de 15%, temperatura de amestecare a fost de 185°C și viteza de amestecare a fost de 25 rpm. S-au determinat rezistența și indicatorii operaționali-tehnologici ai calității unui compozit polimeric termoplastic pentru talpa încălțămintei pe bază de copolimer de etilenă-acetat de vinil și clorură de polivinil în suspensie. S-au dezvoltat ecuații de regresie care să indice dependența proprietăților de deformare și rezistență de factorii tehnologici ai procesului de obținere a compozitelor polimerice pentru tălpi. S-a dovedit că prin selectarea valorilor optime ale parametrilor tehnologici este posibilă obținerea unui singur material cu rezistență mare la deformare și caracteristici tehnologice operaționale.

CUVINTE CHEIE: copolimer de etilenă-acetat de vinil, clorură de polivinil în suspensie, planificarea matematică a experimentului, indicator de calitate generalizat, grad de dezirabilitate.

OPTIMISATION DES VALEURS DES PARAMÈTRES TECHNOLOGIQUES AFIN D'OBTENIR UNE COMPOSITION POLYMÈRE THERMOPLASTIQUE POUR LES SEMELLES POUR CHAUSSURES

RÉSUMÉ. Ce travail révèle la dépendance de la composition et des paramètres de production sur les propriétés d'une composition polymère thermoplastique à base d'un copolymère d'éthylène-acétate de vinyle et du chlorure de polyvinyle en suspension (EVA/PVC-S), ainsi que le choix de la composition du mélange et trouver les paramètres technologiques optimaux pour sa production. Des compositions polymères thermoplastiques pour les semelles ont été obtenues par la méthode de mélange thermomécanique. Pour décrire les propriétés des compositions polymère, en fonction du rapport des composants et des paramètres technologiques d'obtention, la méthode de planification mathématique – « Expérience factorielle complète » de type № = 2^k a été choisie, ce qui permet d›obtenir des estimations séparées des effets linéaires et interactions à deux ou trois facteurs. Dans ce travail, pour construire un modèle mathématique, les facteurs suivants ont été sélectionnés : la teneur en EVA dans la composition, la température et la vitesse de mélange, et on a utilisé les équations de régression lors de l'obtention d'un nouveau type de matériau pour les semelles pour chaussure en utilisant une méthode expérimentale entièrement factorielle. Des résultats optimaux ont été obtenus lorsque la teneur en EVA de la composition polymère était de 15 %, la température de mélange était de 185°C et la vitesse de mélange était de 25 tr/min. La résistance et les indicateurs opérationnels et technologiques de la qualité d'une composition de polymère thermoplastique pour les semelles à base d'un copolymère d'éthylène-acétate de vinyle et du chlorure de polyvinyle en suspension ont été déterminés. Des équations de régression pour la dépendance des propriétés de déformation et de résistance aux facteurs technologiques de la production de compositions polymère pour les semelles ont été construites. Il a été prouvé qu'en sélectionnant les valeurs optimales des paramètres technologiques, il est possible d'obtenir un matériau pour les semelles avec une résistance à la déformation et des caractéristiques technologiques opérationnelles élevées.

MOTS CLÉS : copolymère d'éthylène-acétate de vinyle, chlorure de polyvinyle en suspension, planification mathématique de l'expérience, indicateur de qualité généralisé, fonction de désirabilité.

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INTRODUCTION

Analysis of scientific and technical literature shows that thermoplastic polymer compositions based on a copolymer and thermoplastic, obtained by the method of "mechanical" mixing, in terms of their properties, occupy an intermediate position between thermoplastic and elastomeric polymers. They are considered as two-phase heterogeneous systems in which the copolymer layer is distributed over a thermoplastic matrix [1].

Such thermoplastic polymer compositions with a high range of properties are promising for use in the footwear industry.

It is known that the properties of such complex heterogeneous polymeric materials as thermoplastic polymer compositions based on a copolymer of ethylene with vinyl acetate and suspension polyvinyl chloride (EVA / PVC-S) depend both on the ratio of the initial components and on the technological parameters of production.

However, systematic studies to optimize the technological parameters of obtaining a thermoplastic polymer composition (TPK) based on EVA / PVC-S, taking into account the ratios of the main components, have not been carried out. In the literature, there are only indications that thermoplastic polymer compositions based on a copolymer-thermoplastic are obtained at high temperatures and shear rates, and the resulting material is characterized by flow instability during processing. In addition, different authors [1, 2] obtained thermoplastic polymer compositions of the same composition, but sharply differing from each other in the values of physical and mechanical parameters, which ultimately indicates a very high dependence of properties on both the composition and technological parameters.

Therefore, at this stage of the study, it is advisable to identify the dependence of the composition and technological parameters of production on the properties of a thermoplastic polymer composition, as well as to select the optimal composition of the mixture and find the optimal technological parameters for its production.

EXPERIMENTAL PART

In this work, the main object of the study was suspension polyvinyl chloride grade 6346 M with the trade name "Suspension polyvinyl chloride" produced by JSC "Navoiyazot" in Navoiy (Republic of Uzbekistan) and a copolymer of ethylene with vinyl acetate (vinyl acetate content 18%) with the trade name "Sevilen" produced JSC "Orgsintez", Kazan (Russia), the main characteristics of which are shown in Table 1.

Table 1: Main characteristics of the studied polymers

№	The name of indicators	SEVA (VA-18%)	PVC-S-6346-M
1	Appearance	granules	powder
2	GOST or TU	11507-70	14332-78
3	Molecular weight, thous.	30-500	10 -150
4	Solubility parameters, (cal / cm^3) 1/2	8.4	9.4
6	Density, kg / m^3	0.944	1.34
7	Tensile strength, MPa (not less)	8.0	25
8	Elongation at break, %	800 -700	50
9	Residual elongation at break, %	More than 100	10
10	Vicat heat resistance, °C	100	150
13	Melting point, °C	125	150-220
14	Glass transition temperature, °C		105
15	Crystallinity, %		10
16	Thermal stability at 180 °C, min		190

The choice of these polymers as the main object of research is due to a complex of valuable properties, the possibility of obtaining a thermoplastic polymer composition based on them and processing them into a product on high-performance injection molding units, a stable raw material base, and a relatively low cost of these polymers.

In addition, one of the important characteristics of PVC is the temperature of the beginning of its decomposition and thermal stability. Thermal stability is the time (in minutes) of heating it at a certain temperature until the first signs of the release of toxic gases. Suspension polyvinyl chloride has the highest thermal stability. Therefore, to obtain a thermoplastic polymer composition for the bottom of shoes used in dry and hot climates, this polymer brand was chosen [3].

Polymer compositions based on mixtures of polymers were obtained by the method of thermomechanical mixing under certain conditions in the mixing chamber of a plasticorder manufactured by Brabender (Germany) model PLV-651. Plasticorder specifications:

Loading volume 60-600 cm^3

Front rotor speed 2-150 rpm

The temperature of the mixing chamber is 18-300°C.

The plasticorder is equipped with a device for registering and recording the torque on the shaft.

The technology for manufacturing polymer mixtures consists of the following operations:

1. Preparation of raw materials and ingredients.
   1.1. Drying of polymers.
   1.2. Grinding caked ingredients.
2. Mixing of components.
   2.1. Mixing and melting of the thermoplastic with the copolymer was carried out in the mixing chamber of the plasticorder with constant intensive stirring at a temperature 10-40°C higher than the melting temperature of the thermoplastic for 2-6 minutes.
3. Cooling and granulation.
   3.1. The resulting homogeneous thermoplastic mixture was cooled on cold rollers.
   3.2. Granulation was carried out on a Marris granulator (Italy). As a result of granulation, granules with a size of 2-4 mm were obtained.
4. Recycling. To increase the homogeneity of the mixture, the composition was re-melted, cooled and granulated.
5. Samples for testing were obtained by pressing on vulcanizing presses and by casting on an automatic plating machine from Marris (Italy). The size of the test pieces is 250x130x8 mm.

To assess the qualitative and quantitative indicators of the properties of thermoplastic polymer compositions, standard and original research methods were used with the use of modern equipment and devices given in Table 2.

Table 2: Methods for determining the physical, mechanical and thermophysical indicators of polymer compositions

№	Research methods	Standard number	Applied equipment
1	Tensile strength, elongation and permanent elongation at break	GOST 270 GOST 7926	Tensile testing machine RMI-250 for determination of ultimate strength and elongation at break.
2	Slip resistance coefficient	GOST 4.387	Tearing torsion machine RT-250M with a special device for determining the frictional properties of the bottom of the shoe.
3	Sole attachment strength	GOST 22307	A torsional tearing machine RT-250M with a special device for determining the strength of fastening the bottom of the shoe.
4	Hardness	GOST 263	Hardness tester IT-5078 for measuring the hardness of rubber Shore A
5	Abrasion resistance	GOST 426	MI-2 machine for determination of abrasion resistance of rubbers and rubber products.

№	Research methods	Standard number	Applied equipment
6	Thermal conductivity	GOST 23630.2	IT-1 device for determining thermal conductivity.
7	Density	GOST 267	Hydrostatic method
8	Flexural resistance	GOST 422	Machine MRS-2 for testing the repeated bending of rubbers for the bottom of shoes.
9	Heat resistance	GOST 15088	A device for determining the Vicat softening temperature of thermoplastics in air.

The rheological properties of the studied polymer compositions were judged by the effective viscosity of the melt.

The effective viscosity of the melt was determined by the torque on the plasticorder shaft at a given temperature and rotor speed.

The studies were carried out on a traditional PLV-651 rheometer manufactured by Brabender (Germany), equipped with a special attachment with a N60H mixing chamber volume.

The effective viscosity of the polymer composition was calculated by the formula:

$$\eta_{eff} = \tau/\gamma, \text{ Pa}\bullet\text{s} \quad (1)$$

from here:

$$\tau = M_{кр}/V_{load}; \quad (2)$$

$$\gamma = \pi\bullet n/30; \quad (3)$$

Substituting the values of τ and γ from formulas (2) and (3) into formula (1), we obtained

$$\eta_{eff} = Mcr\bullet 30/\pi \bullet n\bullet V_{load}, \text{ Pa}\bullet\text{s}$$

where: η_{eff} - effective viscosity, Pa•s;

τ - shear stress, N/m^2, Pa;

γ - shear rate, s-1;

$M_{кр}$ - torque on the plasticorder shaft, N • m;

V_{zagr} - the volume of the composition in the mixing chamber, m^3;

n - is the number of revolutions of the rotor, rpm.

Recently, for the solution of optimization problems of chemical-technological processes, methods of mathematical planning of experiments, based on the widespread use of electronic computers, have become widespread.

In this work, to describe the properties of polymer-sole compositions based on EVA / PVC-S, depending on the ratio of components and technological parameters of production, the method of mathematical planning is chosen – "Full factorial experiment" of type No. = 2^k, which makes it possible to obtain separate estimates of linear effects and two, three-factor interactions [4].

To construct a mathematical model, the following factors were selected: the content of EVA in the composition, temperature and mixing rate. The values of the variation factors are presented in Table 3.

Table 3: Factors of variation when planning an experiment by the method "Complete factorial experiment"

Factors	Designation	Factor value at the level of variables, conventional units		Step variations
		-1	+1	
The content of EVA in the polymer-plantar composition, wt.%	X_1	15	40	5
Mixing temperature, ºC	X_2	175	200	5
Displacement speed, rpm	X_3	25	50	5

The output characteristics of the strength and operational and technological properties of polymer-sole compositions were complex indicators of the quality of the material being developed, consisting of 11 single quality indicators, identified as a result of an expert survey of specialists.

U_1 - ultimate strength at break, MPa;

U_2 - elongation at break, %;

U_3 - residual elongation at break, %;

U_4 - slip resistance, conventional units

U_5 - the strength of the sole attachment, kN/m;

U_6 - Shore A hardness, conv. units;

U_7 - abrasion resistance, mm^3;

U_8 - thermal conductivity, W/m • K;

U_9 - density, g/cm^3;

U_{10} - resistance to multiple bending, thousand cycles;

U_{11} - heat resistance, °C

Regression equations describing the quantitative relationship between variables can be represented as a polynomial:

$$\hat{Y}= b_0+ b_1 x_1+ b_2 x_2+ b_3 x_3+ b_{12} x_1 x_2+ b_{13} x_1 x_2+ b_{23} x_2 x_3+b_{123} x_1 x_2 x_3, \quad (1)$$

where: $\hat{Y}$ - values of the criterion;

b_0 - free member;

b_1, b_2, b_3 - linear coefficients;

b_{12}, b_{13}, b_{23} are the double interaction coefficients;

b_{123} is a coefficient that determines the triple interaction of factors.

The planning matrix and the results of the experiment are shown in Table 4.

Table 4: Planning matrix and experiment results

№ experi-ence	Factors planning			Output parameter values										
	X_1	X_2	X_3	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}
1	-1	-1	-1	12.2	250	20	1.0	4.5	75	18.2	0.180	1.21	95	115
2	+1	-1	-1	3.9	80	10	0.8	2.3	79	14.2	0.235	1.18	12	90
3	-1	+1	-1	11.8	255	18	0.87	4.7	76	17.3	0.175	1.31	90	105
4	+1	+1	-1	5.2	105	15	0.65	2.7	79	12.6	0.245	1.18	17	86
5	-1	-1	+1	11.2	230	19	0.95	4.2	77	17.8	0.180	1.25	80	107
6	+1	-1	+1	4.7	50	8	0.7	2.0	80	13.2	0.220	1.15	15	87
7	-1	+1	+1	9.2	185	15	0.8	3.5	75	17.5	0.190	1.23	85	100
8	+1	+1	+1	4.2	70	10	0.5	1.8	86	12.5	0.252	1.15	20	85

To check the adequacy of the mathematical model, 3 identical experiments were carried out with the values of the levels of variation of the factors equal to 0 (X_1 = 0, X_2 = 0, X_3 = 0), the results of which are shown in Table 5.

Table 5: Checking the adequacy of the mathematical model with the values of the levels of variation of factors equal to 0 (X_1 = 0, X_2 = 0, X_3 = 0)

Level of variation of factors	Factors		
	X_1 The content of EVA in the polymer compositions	X_2 Displacement temperature, ºC	X_3 Displacement speed, rpm
-1	15	175	25
0	27.5	187.5	37.5
+1	40	200	50
Variation intervals	12.5	12.5	12.5

To calculate the regression coefficients, a personal computer program PENTIUM IV was compiled. Data processing, namely, deformation-strength and operational-technological characteristics, was carried out using the FUIL. FAC program.

The significance of the coefficients of the regression equation was checked for each coefficient separately according to the Student's test. Insignificant coefficients were excluded from the regression equation. The values of the coefficients of the regression equation characterize the contribution of the corresponding factor to the value of Y. Therefore, in the center of the plan, three additional parallel experiments are placed and the values of Y_i are obtained.

After that, the significance of the coefficients was assessed by the Student's test.

The tabular value of the Student's test for the significance level ρ=0.05 and the number of degrees of freedom f = 2 tp(f) = 4.3.

Thus, insignificant coefficients that are below the tabular value of the Student's test were excluded from the regression equations.

The adequacy of the obtained equations was checked by Fisher's criterion:

$$F = S_{res}^2 / S_{rep}^2 \; ; \qquad (2)$$

$$S_{res}^2 = \frac{\sum_{i=1}^{8}(y_i - \hat{y}_i)^2}{N-l} \; ; \qquad (3)$$

$$S_{rep}^2 = \frac{\sum_{i=1}^{3}\left(y_u^0 - \bar{y}^0\right)^2}{2} \qquad (4)$$

l is the number of significant coefficients in the regression equation, equal to 4.

Then F = 2 / 0.26 = 7.6. Tabulated value of Fisher's criterion for ρ=0.05, f = 4, f_2 = 2, f_{1-p} (f_1, f_2) = 19.3, F <F_{1-p} (f_1, f_2).

Consequently, the resulting equation adequately describes the experiment.

The regression equations for the dependence of the deformation and strength properties on the technological factors of creating polymer sole compositions are as follows:

- for the indicator "Tensile strength at break":

Y_1=13,36 - 0,85•Z_1 + 0,032•Z_2 + 0,40•Z_3 + 0,0026•Z_1Z_2 + 0,0027•Z_1Z_3 - 0,0027•Z_2Z_3 (МПа); (5)

- for the indicator "Relative elongation at break":

Y_2 = 380.38 - 6.15 • Z_1 - 1.55 • Z_3 (%); (6)

- for the indicator "Residual elongation":

Y_3 = 22.35 - 0.29 • Z_1 (%). (7)

If the top of the shoe is traditionally made of genuine leather or fabric, then the bottom of the shoe is made of polymer compositions. The connection of the bottom of the shoe with the upper is carried out by the glue method or by the method of direct casting onto a protracted blank. The service life of the shoe is determined by the strength of the fastening. The dependence of the influence of the technological parameters of the processing of the composition on the adhesive strength of the fastening of the top with the bottom is determined by the equation:

Y_5 = -1.98 - 0.08 • Z_1 + 0.045 • Z_2 + 0.20 • Z_3 - 0.0012 • Z_2 Z_3 ; (kN/m) (8)

Shoes are used in different climatic conditions, including dry tropical climates. It is believed [6, 7] that the sole material intended for operation in these climatic conditions should have high values of heat resistance and low values of thermal conductivity. This will ensure the shoe's dimensional stability and consumer comfort. The regression equations describing the parameter "Heat resistance of the composition" are as follows:

Y_{11} = 168.1 - 0.79 • Z_1 - 0.23 • Z_2 - 0.17 • Z_3 (°C) (9)

It is believed [6, 7] that the sole material intended for use in dry hot climates should have a minimum thermal conductivity to protect the foot from overheating.

The regression equation describing the "Thermal conductivity of the composition" is:

Y_8 = 0.15 + 0.0023 • Z_1; (W / (m • K)) (10)

When developing polymeric materials for the bottom of shoes, it is necessary to pay special attention to the issues of frictional interaction with the supporting surface.

According to [7-9], the suitability of a certain sole material from the point of view of the safety of a person's movement on a particular surface can be characterized by comparing the static and dynamic coefficients of friction of the contact between the bottom system and the supporting surface. According to this, the static coefficients of friction must be at least 0.7, and the dynamic ones must be at least 0.8.

In this work, to study the coefficient of sliding resistance, a standard surface (for a glass-glazed plate) is taken.

The regression equation describing slip resistance is:

Y_4 = 2.37 - 0.0097 • Z_1 - 0.0063 • Z_2 - 0.0037 • Z_3; (conventional units) (11)

An important ergonomic characteristic of the sole composition, in terms of ease of wear, is its density.

The approximate dependence of the density on the investigated technological factors is described by the equation:

Y_9 = 1.30 - 0.0034 • Z_1; (g / cm^3) (12)

Hardness is one of the most important characteristics of the technological and operational properties of polymeric materials used for the manufacture of shoe bottom parts. This indicator largely determines the possibility of using a polymer composition for a particular type and purpose of footwear. The dependence of the hardness (Y_6) of the composition on the investigated factors is as follows:

Y_6 = 78.375; (conventional unit according to Shore, scale A) (13)

When using shoes, their contact with the supporting surface and the human body is permanent. As a result, the surface of the rubbing parts is destroyed and wears out [6-9].

The work investigates the abrasion resistance of the samples obtained as a result of the optimization of the experiment. The resulting regression equation describing the dependence of abrasion resistance on the factors investigated has the form:

$Y_7 = 35.93 - 0.18 \bullet Z_1 - 0.08 \bullet Z_2 - 0.24 \bullet Z_3 + 0.0012 \bullet Z_2 Z_3$; ($mm^3$) (14)

It is known that footwear undergoes multiple bending during operation. The approximate dependence of multiple bending on the investigated factors is described by the equation in the form:

$Y_{10} = 130.4 - 2.86 \bullet Z_1$; (thousand cycles) (15)

The analysis of the obtained mathematical models (5-15) is of certain interest for identifying the nature of the influence of the factors considered.

The analyzed factors have an ambiguous effect on the considered single indicators: if an increase in the values of factors has a positive effect on the hardness, i.e. with an increase in the value of the factors, the strength indicator increases, then on the output characteristics: elongation at break, thermal conductivity, slip resistance, multiple bending - the effect is negative.

For other indicators, the influence of factors is not unambiguous.

The complexity of the interpretation of the obtained results of the study lies in the fact that at present the mechanism of the formation of a thermoplastic polymer composition has not been fully elucidated, and it is practically impossible to recreate the complete picture of the process from some responses.

However, for some indicators, the mechanism of the process is obvious, for example, for equation (5) - tensile strength at break. Factor X_1 - the amount of EVA in the composition has a negative value and a relatively lower value, which can be logically explained from the point of view of the additivity of the properties of the mixture. Replacing the amount of a low strength component with a high strength component results in an increase in tensile strength values for the entire composition. Influence of factors: the temperature and mixing rate on the strength indicator is much lower than for the EVA content factor.

Paired interactions of factors: $X_1 X_2$ and $X_1 X_3$ are positive. Paired interactions $X_2 X_3$ have a negative effect: with an increase in the values of technological properties, the strength of the resulting composition decreases.

For this system EVA : PVC-S in the considered range of compositions, it is unlikely to achieve a significant increase in strength, since all coefficients for linear, paired and triple terms of the equation have a negative value.

One of the most important indicators of synthetic sole materials is the ability to cast, that is, the rheological behavior of the material under the influence of temperature and external conditions.

In this work, effective viscosity is taken to study the rheological properties.

The conducted research shows that an increase in the volume of the crystalline phase, temperature, mixing rate and the pairwise interaction of temperature with the rate decreases the value of the effective viscosity.

Based on the results obtained, a curve of viscosity change versus temperature and shear rate was constructed (Fig. 1).

The viscosity of such compositions in the investigated range of parameter changes depends to a greater extent on the shear rate than on temperature [10, 11].

This appears most clearly in the following ranges of values of the factors under consideration.

X_1 =15-20, X_2 =185-190, X_3 =25-30

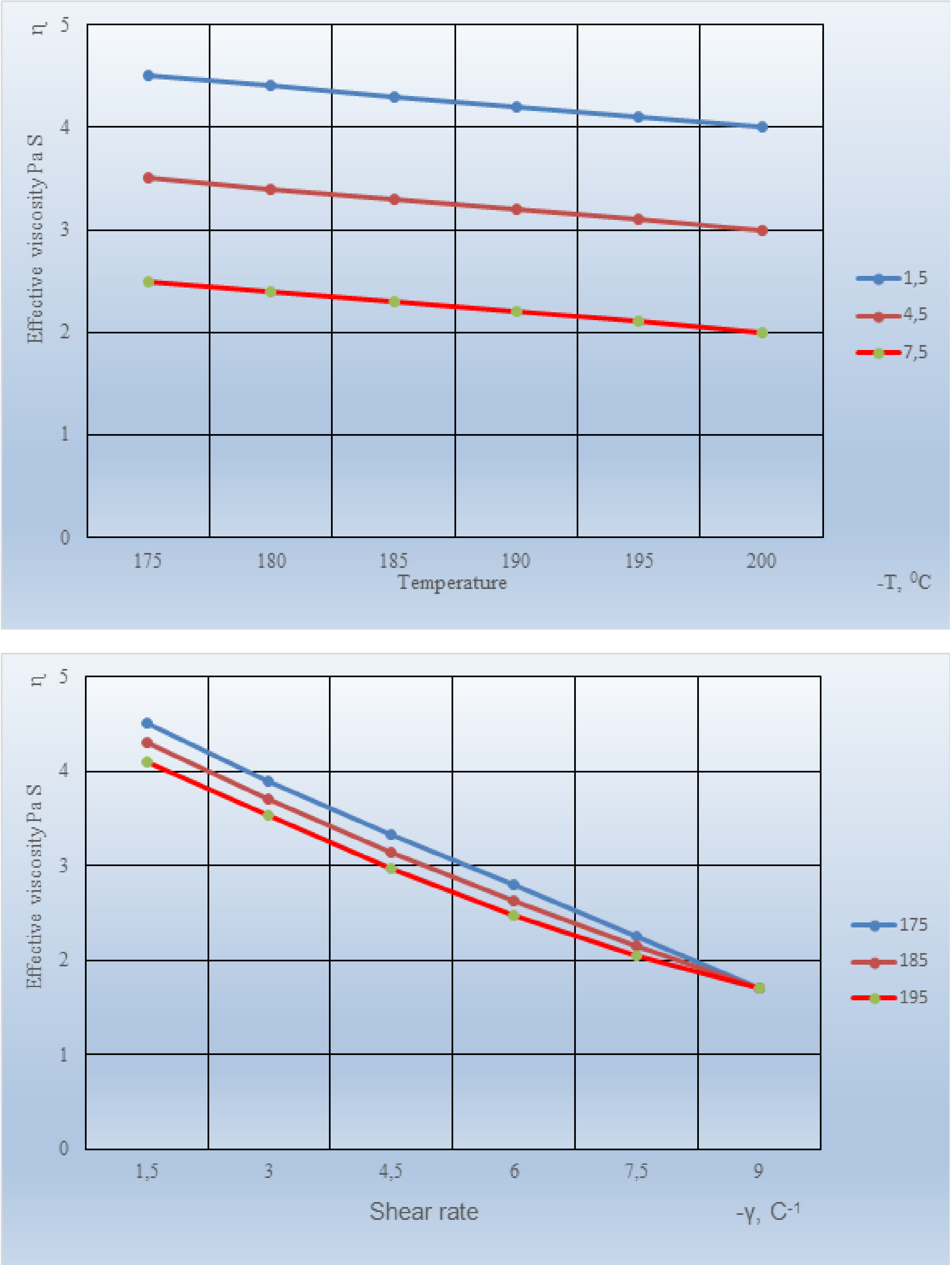

Figure 1. Dependence of the viscosity of a thermoplastic polymer composition based on PVC / EVA in the ratio 0.85 / 0.15 on temperature (a) and shear rate (δ)

Thus, considering the above equations, we can say that a scientifically grounded choice of the values of the factors X_1, X_2 and X_3, at which the optimization parameter Y_i reaches its maximum value, is possible only if a special mathematical apparatus is used.

RESULTS AND DISCUSSION

One of the most successful ways to solve the problem of optimizing processes with a large number of responses is to use the Desirability Function method proposed by Harrington [4, 5, 13]. The method consists in converting single quality indicators (Y_i), expressed on a physical scale, into a dimensionless indicator (Y_i'). Conversion of Y_i' into the values of unit quality indicators (di), which can be carried out either by the graphical method shown in the figure (Figure 2), or by the analytical method according to the dependence:

$$d_i = exp\left(-exp\left(-Y'_i\right)\right) \quad (16)$$

The generalized quality indicator (D), combining all the single ones into a complex indicator, was determined by the dependence:

$$D = \sqrt[n]{d_1 d_2 d_3 \ldots d_n} \quad (17)$$

where: D - generalized quality indicators, calculated according to a simplified method, taking into account the weight of single quality indicators;

$d_1, d_2, d_3, \ldots d_n$ are particular desirability functions;

Y_i - the desired value of the natural indicator of the i-th property;

i = 1 … 11- quality indicator numbers.

The resulting mathematical model of the generalized quality indicator (D), for the study area, has the form:

$$D = \left[exp\left(-\frac{1}{11}(0{,}127\ \exp\left(-0{,}70 + 0{,}44\,Y_1\right) + 0{,}111 exp(-0{,}65 + 0{,}0086\,Y_2) + 0{,}106\,exp(3{,}48 - 0{,}066\,Y_3) + 0{,}091\,exp(-1{,}27 + 3{,}95\,Y_4) + 0{,}088\,exp(-1{,}64 + + 1{,}16\,Y_5) + 0{,}081\,exp(-3{,}11 + 0{,}066\,Y_6) + 0{,}075\,exp(-0{,}52 + 0{,}20\,Y_7) + 0{,}075\,exp(2{,}82 - 6{,}59\,Y_8) + 0{,}070\,exp(12{,}37 - 9{,}88\,Y_9) + 0{,}065\ exp(-1{,}32 + 0{,}056\,Y_{10}) + 0{,}061\,exp(-3{,}44\ + 0{,}049\,Y_{11}\right)\right)\right] \quad (18)$$

Where $Y_1 \ldots Y_{11}$ - natural values of the quality indicator.

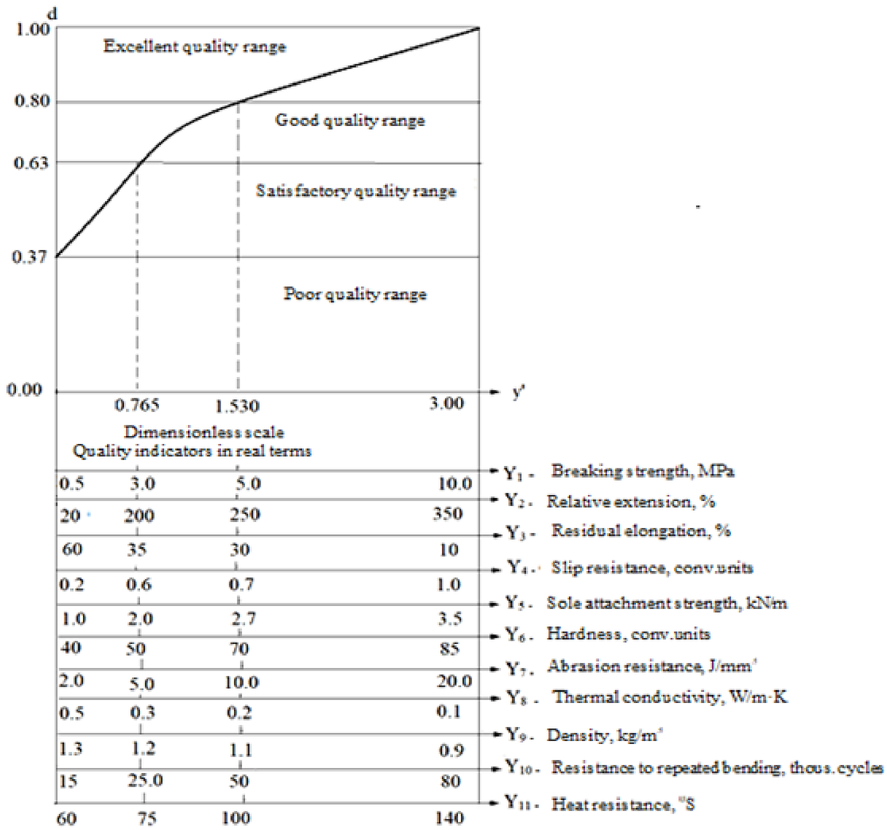

Figure 2. The function of desirability and the scale of assessing the quality indicators of the polymer composition for the bottom of the shoe

Therefore, to select the optimal value of the factors (X_1, X_2, X_3), with the optimal operating and technological parameters, the Desirability Function method was used [12].

The scale of assessing quality indicators and the graph "Desirability function" are shown in Fig. 2.

Based on the calculations, the generalized quality indicator is recognized as the best composition with the maximum value of D, i.e. having the best set of values of consumer characteristics.

The optimal values of the factors X_1, X_2, X_3, at which D = 0.84, which corresponds to excellent quality, are equal to:

X_1 = 15 mass. %; X_2 = 187°C; X_3 = 25 rpm.

The results obtained under these conditions - tensile strength at break is 12.0 MPa, elongation - 249%, residual elongation - 18%, slip resistance - 0.95 conventional units, adhesive bond strength - 4.56 kN/m, Shore hardness 78 conv. units, resistance to abrasion - 17.9 mm^3, thermal conductivity - 0.18 W / m • K, density - 1.25 g / cm^3, resistance to multiple bending - 87.5 thousand cycles, heat resistance - 110°C.

The calculation results show that the consumer and technological properties of the polymer-sole composition vary in a wide range depending on the input parameters.

CONCLUSION

Thus, by selecting the optimal values of technological parameters for obtaining thermoplastic polymer compositions, it is possible to obtain a sole material with high deformation-strength and operational-technological characteristics.

The obtained mathematical equations (5) - (15) should be used to create a computer-aided design system for the manufacturing of shoe bottom parts based on domestic suspension polyvinyl chloride and ethylene-vinyl acetate copolymer by injection molding.

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DESIGNING OF THE SHOE UPPER USING MODERN INFORMATION AND COMPUTER TECHNOLOGIES

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DESIGNING OF THE SHOE UPPER USING FOOT NUMERICAL CHARACTERISTICS AND MODERN COMPUTER TECHNOLOGIES

ABSTRACT. The article presents the process of designing the details of shoe upper for schoolchildren using the numerical characteristics of the feet and modern computer technology. A software module for processing the obtained data in the MathCad Education program has been developed, which allows to create parametric models of the foot and longitudinal-vertical section of the internal shape with a deviation of not more than 5%. It is established that developing parametric aspects of shoe upper design is advantageous in the age range from 11 to 13 years. Patterns between different parameters of schoolchildren's feet are also determined. On the basis of the developed parametric models and the proposed principles of modular transformation the construction of low shoes (half-boots) is designed and made.

KEY WORDS: foot, design, shoe design, computer technology

PROIECTAREA FEȚELOR DE ÎNCĂLȚĂMINTE UTILIZÂND DATELE ANTROPOMETRICE ALE PICIOARELOR ȘI TEHNOLOGII COMPUTERIZATE MODERNE

REZUMAT. Articolul prezintă procesul de proiectare a detaliilor feței de încălțăminte pentru școlari folosind datele antropometrice ale picioarelor și tehnologia computerizată modernă. S-a dezvoltat un modul software pentru procesarea datelor obținute cu ajutorul programului MathCad Education, care permite crearea unor modele parametrice ale piciorului și secțiunii longitudinal-verticale a formei interne cu o abatere de cel mult 5%. S-a stabilit că dezvoltarea aspectelor parametrice ale designului fețelor de încălțăminte este avantajoasă pentru copii cu vârsta cuprinsă între 11 și 13 ani. S-au determinat și tiparele diferiților parametri ai picioarelor școlarilor. Pe baza modelelor parametrice dezvoltate și a principiilor de transformare modulară propuse s-a proiectat și realizat construcția încălțămintei joase (ghete scurte).

CUVINTE CHEIE: picior, design, design de încălțăminte, tehnologie computerizată

LA CONCEPTION DE LA TIGE DE LA CHAUSSURE À L'AIDE DE DONNÉES ANTHROPOMÉTRIQUES DES PIEDS ET DE TECHNOLOGIES INFORMATIQUES MODERNES

RÉSUMÉ. L'article présente le processus de conception des détails d'une tige de la chaussure pour écoliers en utilisant les données anthropométriques des pieds et la technologie informatique moderne. Un module logiciel de traitement des données obtenues dans le logiciel MathCad Education a été développé, ce qui permet de créer des modèles paramétriques du pied et de la section longitudinale-verticale de la forme interne avec un écart ne dépassant pas 5%. Il est établi que le développement des aspects paramétriques de la conception de la tige de la chaussure est avantageux dans la tranche d'âge de 11 à 13 ans. Les modèles des différents paramètres des pieds des élèves ont également été déterminés. Sur la base des modèles paramétriques développés et des principes de transformation modulaire proposés, la construction de chaussures basses (bottes courtes) a été conçue et réalisée.

MOTS CLÉS : pied, conception, conception de chaussures, technologie informatique

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INTRODUCTION

The efficiency of shoe companies, their adaptation to today's market requirements and consumer demand depends on the assortment policy, the possibility of mobility of production and competitiveness of products. The shoes must be of high quality, meet the anatomical and morphological requirements and fashion trends. In addition, the production of footwear should ensure the cost-effectiveness and profitability of its design and manufacture; the range should be as standardized, unified and consistent with the existing production base.

One of the ways to solve these problems is the design and manufacture of footwear in mass production on the basis of highly efficient technologies. It is advisable to use a comprehensive system of computer-aided design of footwear [1], which allows to take into account the diverse requirements for product quality, shaping their internal form [2, 3] and combine individual characteristics of consumer feet with industrial methods of their design and production.

In the range of footwear, insufficient attention is paid to the production of items for schoolchildren. The issues of expanding the range of footwear for schoolchildren [4] and ensuring a high level of quality and design criteria are especially relevant.

Today, students choose active hobbies, which significantly affects consumer demand for shoes. In addition, in recent decades, due to the impact of the acceleration process, there has also been a change in the parameters of length, width and foot circumference of schoolchildren. Therefore, the creation of comprehensive automated systems for designing shoes for schoolchildren should be carried out considering the modern anthropometric data, the requirements of regulatory documents, the level of psychophysiological development of children, improved methods of shoe design.

The application of the achievements of modern technologies at different stages of design and technological preparation for schoolchildren footwear production allows not only to reduce the production time of new models and the cost of development, but also to improve the quality of footwear.

EXPERIMENTAL

Materials and Methods

The research methodology is to determine the anthropometric and morphological [5, 6] characteristics of schoolchildren's feet, to develop methods of processing the obtained data as parametric models, to develop theoretical preconditions for the development of shoe models for schoolchildren. In particular, this concerns the development of a method of contour profiling using spline curves [7-12], which provides analytical modules for designing the upper part of shoes for students while considering the anatomical and morphological features of the feet.

RESULTS AND DISCUSSIONS

Experimental studies of the process of automated design of shoe uppers for schoolchildren consist of several stages and each of them takes into account the anthropometry and morphology of the feet. Also, studies involve the use of spline curves with curvilinear guides and modular transformation.

The first stage was to determine the distribution of foot lengths according to the age of students. The dependency graph of foot length and girls' age is presented in Fig. 1.

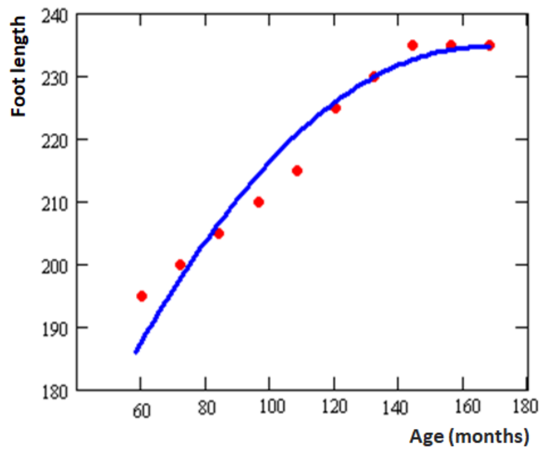


Figure 1. Dependence of foot length on age for the girls group

It is established [13] that these dependences are best approximated by a function of the form:

$$L(v) = 2 \cdot L_m \cdot \left(\frac{v}{v_{max}} - \frac{v^2}{2 \cdot v_{max}^2} \right) + L_0 \qquad (1)$$

where v – age of schoolchildren in months;

L_m – limit value of foot length, mm;

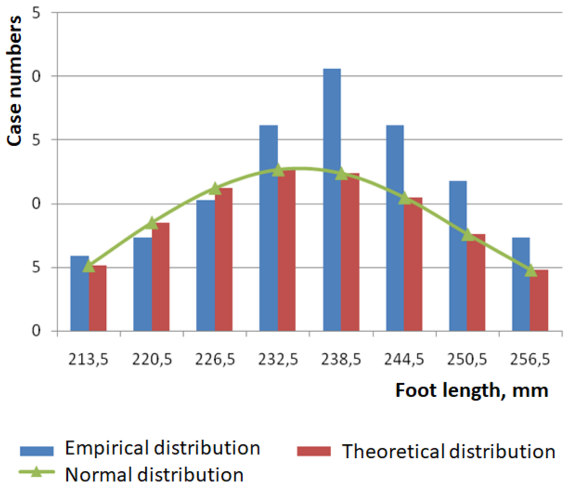
v_{max} – maximum value of months;

L_0 – initial value of foot length (length of foot at birth), mm.

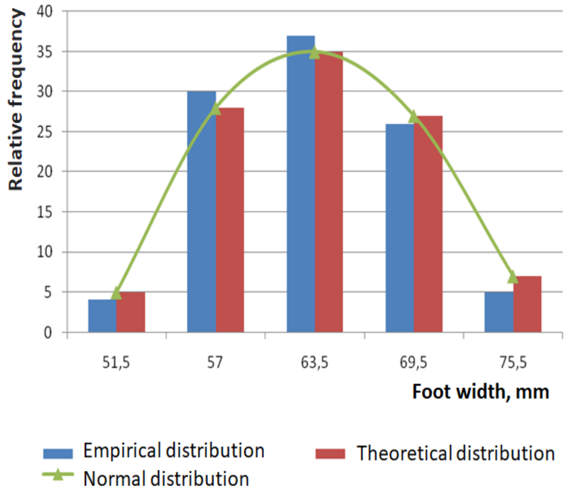
On the basis of the given dependences, coefficients of ratios with an error no more than 5% are defined. The obtained research results and dependences allow establishing the dynamics of growth of schoolchildren's feet, to determine the age limits for which it is most expedient to develop parametric aspects of shoe design.

Then anthropometric measurements of schoolchildren were carried out, correlations in dimensional parameters of feet were determined with the subsequent use of the received data for designing of longitudinal-vertical section of internal form and details of top of footwear for the stipulated group of consumers.

Figure 2 shows the empirical and theoretical distribution of length, width and girth of the foot for girls.



a)



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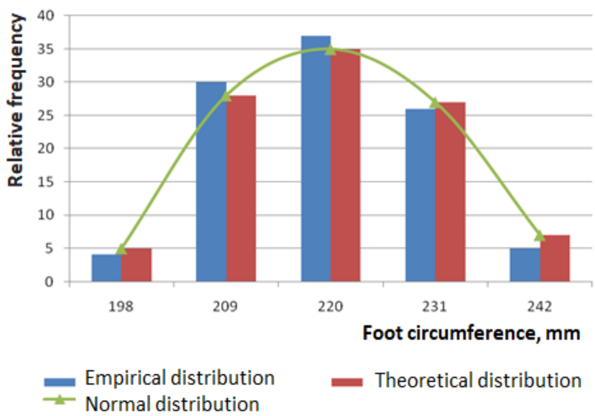


c)

Figure 2. Empirical and theoretical distribution of parameters for girls aged 11-13 years: a) length; b) widths; c) foot circumference

In addition, it was found that the average transverse dimensions of the feet of boys and girls (circumference – C_t та width – W_t) aged 11-13 years are associated with their length L_f orthogonal regression dependence $y=tg\alpha{\cdot}x+b$ [6], which in our case has the form: $O_n = tg\alpha{\cdot} Lf + b_1$.

In Fig. 3, as an example, shows the dependence of the foot length with the foot circumference for girls. The values of the correlation coefficients ranged from 0.51 to 0.75. Similar dependences were obtained for the boys' feet.

The study of the third and fourth patterns showed that the same size of the feet of students have a proportional relationship: long - with the foot length, transverse - foot circumference. Thus, analytical dependences were obtained for the design of the longitudinal-vertical section of the internal shape.

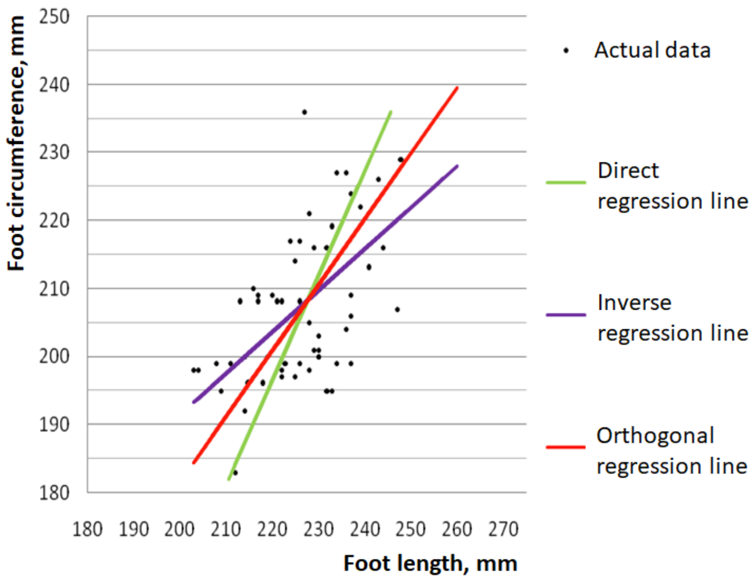


Figure 3. Graph of foot length (mm) with foot circumference (mm) for girls

The revealed distinctive morphological features of feet of schoolboys are showed in Table 1. These features were considered in designing of longitudinal-vertical section of an internal form.

Table 1: Morphological features of schoolchildren's feet

	Morphological features of schoolchildren's feet	Measured girls' feet (11-13 years), %	Measured boys' feet (11-13 years), %
1.	Hypertrophy of the heads of the fifth metatarsal bone	34.5	38.2
2.	Fifth toe muscle hypertrophy	27.6	16.7
3.	Heel outside deviation	39.2	44.3
4.	Hypertrophy of the heads of the first metatarsal bone	53.6	44.5
5.	Combination of hypertrophy of the first and fifth metatarsal bones	35	30
6.	Flat feet of various degrees	12.8	30.6
7.	Claw-shaped toes	25.7	22

The next stage of the study was to develop a method of profiling the outlines of parts, using spline curves, which will reduce the order of the curve of high complexity, including - with the curvature of different signs, which is quite important for designing students' shoes.

Using the developed method, outlines for girls aged 11-13 were obtained and the coordinates of control points were determined. In Fig. 4 is shown a comparison of obtaining the foot outline for 11–13-year-old girls using spline curves with curved guides and spline curves with straight guides. Due to the use of spline curves with curved guides, the curve passes more accurately through all the characteristic anatomical points, especially in the heel.

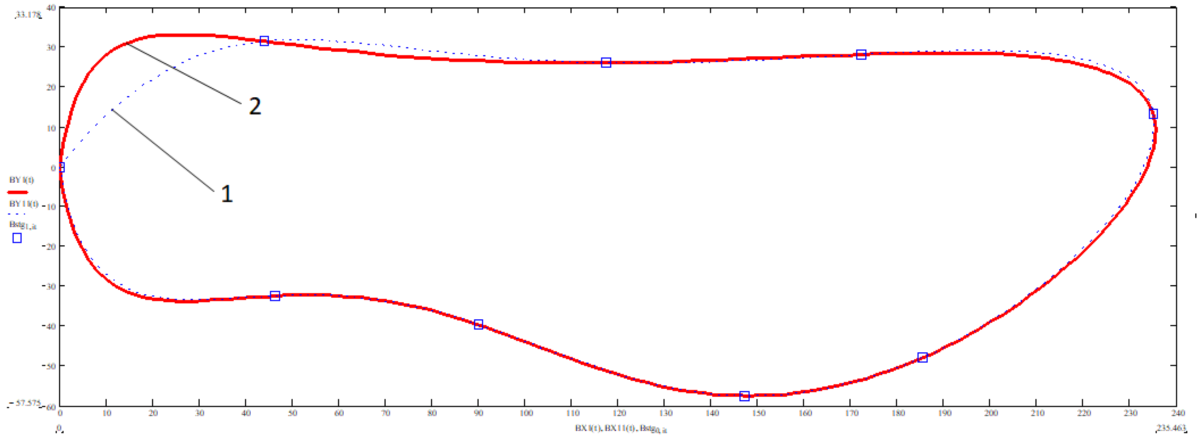


Figure 4. Comparison of footprint outline identification of girls aged 11-13 years with the use of: 1 - curvilinear guides, 2 - rectilinear guides

On the basis of the developed method the algorithm of automatic calculation of coordinates of feet outline curve with various lengths for 11–13-year-old girls is formed (Fig. 5).

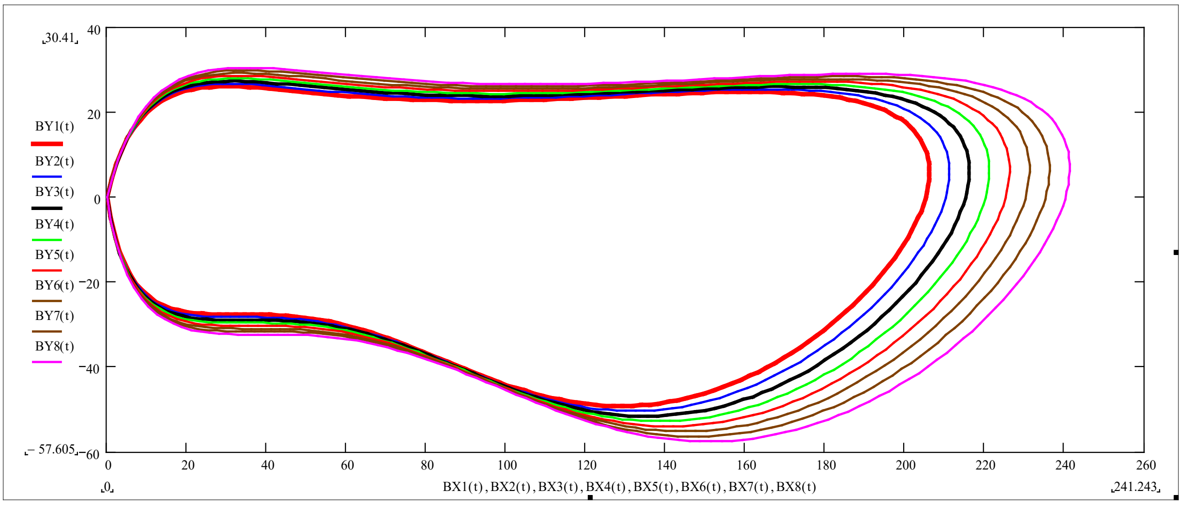
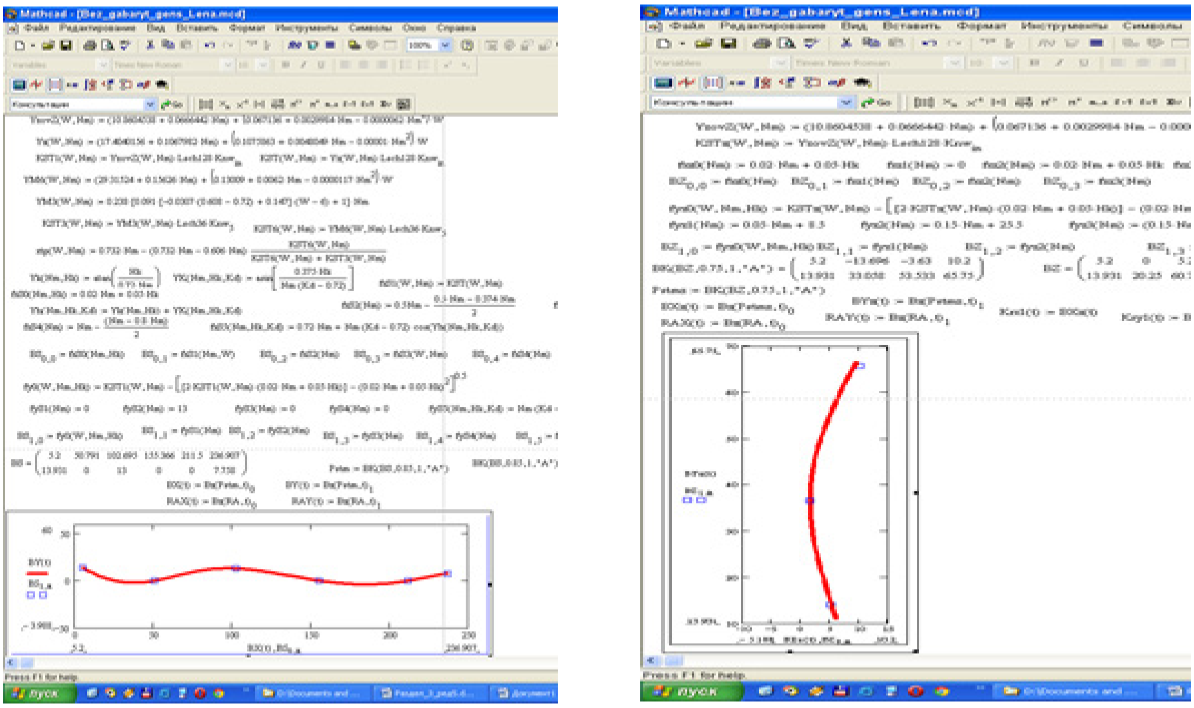
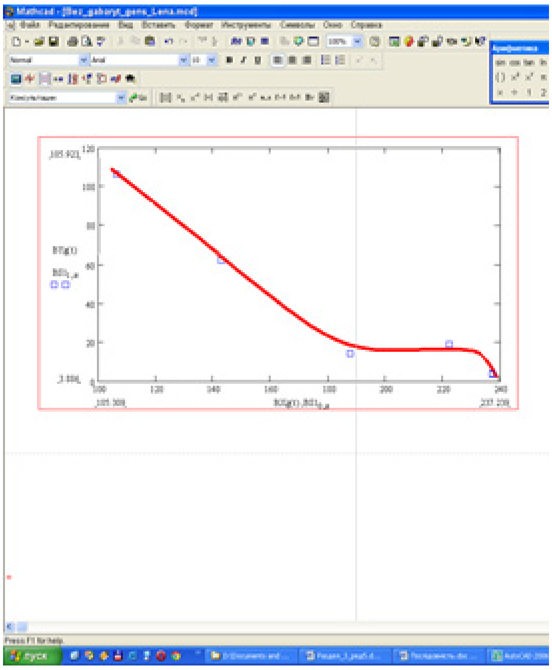


Figure 5. Comparison of outline curves for foot length from 205 to 255 mm for 11–13-year-old girls

Analytical bases of calculation of spline points coordinates for curves with circular curvilinear guides for the basic types combinations of sites are developed (the beginning - curvilinear convex, final - rectilinear; the concave circular guide - rectilinear guide, the convex curvilinear guide - concave, etc.). Blocks for calculation of spline points coordinates for curves with circular curvilinear are also developed. Software modules are compiled in the MathCAD computer system (Fig. 6).





c)

Figure 6. Software module for process of parametric designing the shoe upper details: a) the outline of the trace; b) heel contour; c) the outline of the apex

The software module for process of parametric designing the shoe upper details gives possibility for quickly implement a new range of shoes, while ensuring high accuracy and quality of design.

The term "modular transformation" is proposed to use for developing schoolchildren's shoe designs. This method means converting one form of construction into another or changing a part within this form using known dedicated modules.

The main design features of modular transformation:

– taking into account the anatomical features of the feet;

– adherence to the basics of shoe design;

– preservation of product functionality;

– manufacturability of the structure;

– providing ergonomic requirements for shoes for schoolchildren;

– aesthetics.

On the basis of the developed parametric models and the proposed principles of modular transformation the low shoes were designed and made (Fig. 7).

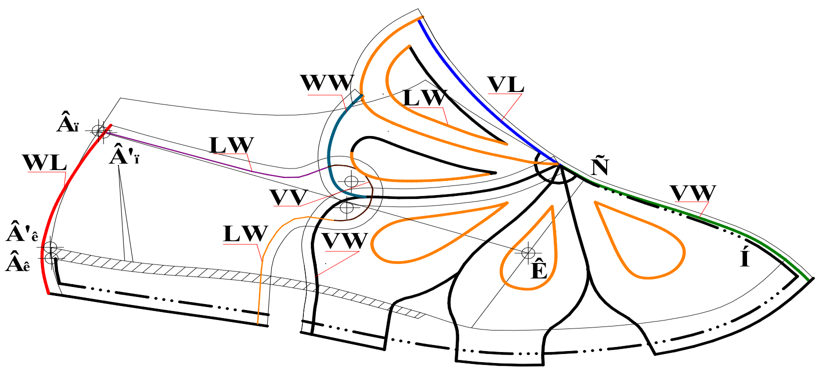


Figure 7. Design of the low shoes using spline curves with curved guides

In Fig. 7, the following designations of combinations of spline curves depending on the generally accepted principles of footwear designing are accepted:

WL initial guide curved convex, final - rectilinear (marked in red);

VL initial guide is curved concave, the final one is rectilinear (marked in dark blue);

WV initial guide curved convex, final - curved concave (marked in green);

VW initial guide rectilinear, final - curvilinear convex (marked in black);

LV initial rectilinear guide, final - curved concave (marked in purple);

LW initial rectilinear guide, final - curved convex (marked in orange);

WW initial guide curvilinear convex, final - curvilinear convex (marked in blue);

VV initial guide curved concave, final - curved concave (marked in brown).

So, as can be seen from Fig. 7, the practical application of the developed software module allows obtaining fundamentally new approaches to the design of uppers shoe for students.

For adequate transition from the calculations and the resulting outlines of the foot of the longitudinal-vertical section of the internal form [14], which are obtained in the computer system MathCAD (PKG-7540-FN Mathacad Education - University Edition) to direct design in AutoCAD used the principles of cloud technology (Fig. 8).

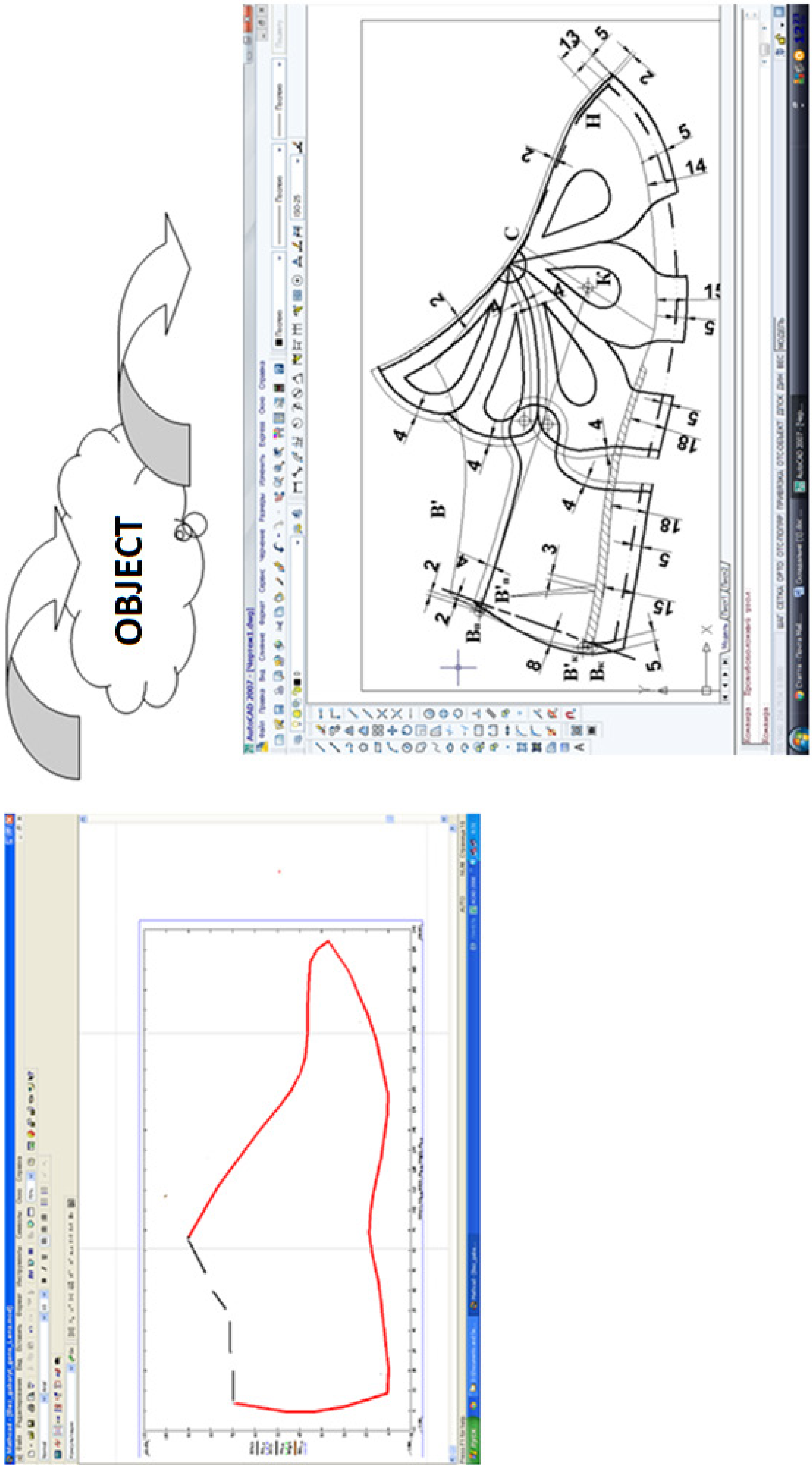


Figure 8. Element of the transition from Mathacad Education to AutoCAD

On the basis of the conducted research, the experimental batch of low shoes for girls (Fig. 9) was made, which was then transferred for carrying out experimental wearing.

Figure 9. Experimental sample of low shoes

According to the experimental wearing results, the experimental batch of low shoes for girls received a positive conclusion, and was launched into shoe production PE "KM-PODILLIA".

CONCLUSIONS

1. The age limits for which it is advisable to develop parametric aspects of shoe upper design are set in 11-13 years.

2. Regularities between different parameters of students' feet are determined:

- frequency distribution of longitudinal, height and transverse sizes of feet (latitudinal and circumferential) with the maximum probability is expressed by the law of normal distribution;
- average circumferential and latitudinal sizes of feet of Ukrainian schoolchildren are connected with their length by orthogonal regression dependence. The absolute values of the error of the regression equations for different parameters range from 0.7 to 7.7 mm, which is very important for shoe design;
- all the same sizes of feet have a close proportional relationship: long - with foot length, transverse - with foot width. This allowed taking into account the real anatomical foot characteristics in the shoe upper design.

3. The software module of received data processing in the MathCad Education was developed, which allows creating parametric models of foot and longitudinal-vertical section of an internal form, with a deviation no more than 5%.

4. The basic principles of modular transformation of footwear for schoolchildren are offered. This approach results in different complexity of product design elements that are interconnected. Application of modular transformation at footwear designing for schoolchildren will allow to receive various transformations of a design on degree of closedness, possibility of the maximum operation of a product and economy on material resources.

5. On the basis of the developed parametric models and the offered principles of modular transformation the low shoes are designed and made. The made experimental batch of low shoes for girls received the positive conclusion on experimental wearing results and was launched into footwear production PE "KM-PODILLIA".

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BIOMECHANICAL FOOT ANALYSIS IN CASE OF FOUR TYPOLOGIES: NORMAL FOOT, PES CAVUS, PES PLANUS AND HALLUX VALGUS

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BIOMECHANICAL FOOT ANALYSIS IN CASE OF FOUR TYPOLOGIES: NORMAL FOOT, PES CAVUS, PES PLANUS AND HALLUX VALGUS

ABSTRACT. As each person is different in terms of conformation of the foot and temporal and spatial peculiarities of the individual gait pattern, an extended biomechanical analysis was performed for four categories of foot identified by the authors in a previous research study, namely normal, pes cavus (high arched), pes planus (flat) and hallux-valgus foot, in the case of young people aged 20-30 years. A representative case study was selected and the plantar pressures obtained in dynamics were analysed, following the next sequence: framing the subject in the appropriate category, simultaneous visualisation of the footprint for the left and right foot, impulse analysis, recording the variation of plantar pressures and the forces exerted on the foot as a function of time, calculating the percentage values of balance on the rear-foot, heel and medial areas, positioning of the foot axis according to the direction of movement, identification of individual characteristics of walking phases and their temporal / spatial characterisation parameters, highlighting the hysteresis for heel and rear-foot areas, recommendations for the application of orthotic devices. These results are significant in the modelling and design of the bottom shoe assembly, thus proposing solutions for balancing the pressures on the plantar surface by choosing the appropriate dimensional and shape characteristics of the components of this assembly.

KEY WORDS: foot biomechanics, gait analysis, customized footwear

ANALIZA BIOMECANICĂ A PICIORULUI ÎN CAZUL A PATRU TIPOLOGII: PICIOR NORMAL, PICIOR SCOBIT, PICIOR PLAT ȘI PICIOR CU HALLUX VALGUS

REZUMAT. Pentru că fiecare persoană este diferită de celelalte prin conformația piciorului său și prin particularitățile temporare și spațiale ale tiparului individual de mers, a fost realizată o analiză biomecanică extinsă pentru patru categorii de picior identificate într-o cercetare anterioară, respectiv picior normal, picior scobit, picior plat și picior cu hallux-valgus, în cazul tinerilor cu vârsta cuprinsă între 20 și 30 de ani. A fost astfel selectat câte un studiu de caz reprezentativ și au fost analizate presiunile plantare obținute în dinamică, parcurgându-se următoarea succesiune: încadrarea subiectului în categoria corespunzătoare, vizualizarea simultană a amprentelor pentru piciorul stâng și piciorul drept, analiza impulsului, înregistrarea variației presiunilor plantare și a forțelor exercitate asupra piciorului în funcție de timp, calcularea valorilor procentuale ale echilibrului pe zonele anterioară, posterioară și mediană, poziționarea axei piciorului în raport cu direcția de deplasare, identificarea caracteristicilor individuale ale fazelor mersului și a parametrilor temporali/spațiali de caracterizare a acestora, evidențierea histerezelor călcâiului și pe cele ale părții anterioare, recomandări pentru aplicarea dispozitivelor ortotice. Aceste rezultate sunt extrem de importante în etapa modelării și proiectării ansamblului inferior al încălțămintei propunându-se astfel soluții pentru echilibrarea presiunilor pe suprafața plantară prin alegerea corespunzătoare a caracteristicilor dimensionale și de formă ale componentelor acestui ansamblu.

CUVINTE CHEIE: biomecanica piciorului, analiza mersului, încălțăminte personalizată

ANALYSE BIOMÉCANIQUE DU PIED DANS LE CAS DES QUATRE TYPES : LE PIED NORMAL, LE PIED CREUX, LE PIED PLAT ET LE PIED AVEC HALLUX-VALGUS

RÉSUMÉ. Parce que chaque personne diffère des autres par la forme de son pied et les caractéristiques temporelles et spatiales du modèle de marche individuel, une analyse biomécanique étendue a été réalisée pour quatre catégories de pied identifiées dans une étude précédente, à savoir le pied normal, le pied creux, le pied plat et le pied avec hallux-valgus, chez les jeunes de 20 à 30 ans. Un cas d'étude représentatif a été sélectionné et les pressions plantaires obtenues en dynamique ont été analysées en suivant la séquence suivante : cadrage du sujet dans la catégorie appropriée, visualisation simultanée des empreintes digitales du pied gauche et droit, analyse des impulsions, enregistrement de la variation des pressions plantaires et les forces exercées sur le pied en fonction du temps, le calcul des pourcentages d'équilibre sur les zones antérieure, postérieure et médiane, le positionnement de l'axe du pied par rapport à la direction du mouvement, l'identification des caractéristiques individuelles des phases de marche et leurs paramètres temporels/spatiaux, mettant en évidence l'hystérésis du talon et celles de la partie antérieure, recommandations pour l'application des orthèses. Ces résultats sont extrêmement importants dans l'étape de modélisation et de conception de l'ensemble inférieur de la chaussure, proposant ainsi des solutions pour équilibrer les pressions sur la surface plantaire en choisissant les caractéristiques dimensionnelles et de forme appropriées des composants de cet ensemble.

MOTS CLÉS : biomécanique du pied, analyse de la marche, chaussures personnalisées

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INTRODUCTION

Plantar footprint has often been studied in the past for various reasons [1-2]. Many scientists around the world have focused their attention on the analysis of traces of hominid fossils, orthopaedic and other medical studies, such as anatomical, anthropological, genetic, dermatological, biomechanical, ergonomic and forensic studies [3].

Biomechanical studies have progressed, by comparing the existence, lack or dimensions of the typological parameters of the foot between groups with or without pathologies under investigation [4]. Despite the widespread use of these parameters, it has been recognized that objective and quantitative analysis of foot typologies remains elusive [5-6]. The absence of an absolute dimension of the foot typology led to considerable variations in the choice of the type of measurements in order to determine the type of foot [7-8]. This is in antithesis with the suggestion that in order to identify the relations between the typology and the pathology of the foot, it is first necessary to use a classification system that allows the accurate recognition of each situation [9-10].

People can be distinguished from each other by their unique gait pattern. This gait pattern is used to recognise people at a distance [11-13]. Because each step is slightly different from the other while walking, due to differences in walking parameters, such as heel contact, speed and angle of rotation, force and effort, variation in human locomotion exists for each individual, even in walking on the same type of ground [14-16].

This article continues the research undertaken by the authors, namely the biomechanical analysis for the four typologies of the foot of young people aged between 20-30 years. Using the Chippaux-Simark index (CIS), vault angle (α), and thumb deflection angle (β), subjects were divided into 4 categories, as follows: subjects with normal, pes cavus (high arched), pes planus (flat), and hallux-valgus foot [17].

EXPERIMENTAL

Methods and Equipment

As the investigated subjects (volunteers) stated that they were not in the records of any specialist and did not report that they were suffering from any condition affecting the health of the foot (e.g., diabetes, rheumatoid arthritis, irreversible structural abnormalities of the foot), the preliminary condition of the study was met, namely the taking of plantar footprint from subjects who are apparently healthy or who declare a good state of health. Under these conditions, by elimination, the only factor that could influence the presence of the flat, the high arched or hallux valgus foot in young people is the wearing of inappropriate footwear. The study highlighted the need to inform consumers about the risks they are exposed to when wearing inappropriate footwear.

In order to establish the typology of the foot, the plantar footprints were taken from a number of 76 subjects, of which 60 are women and 16 men, aged between 20-30 years, and weighing between 45-100 kg.

For all investigated subjects, the following working hypotheses were considered:

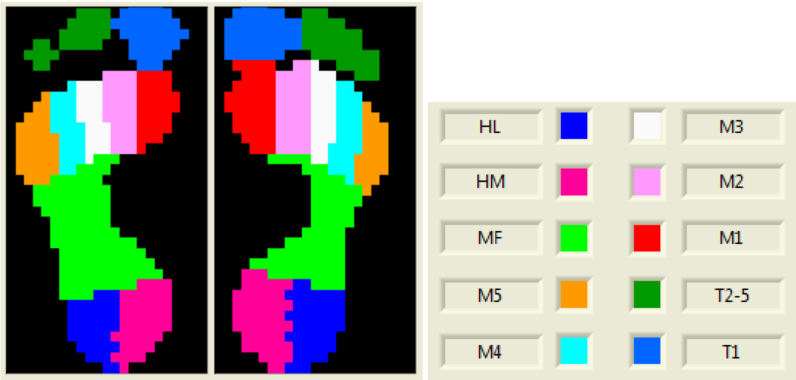
- No abnormal gait patterns were observed;
- No structural abnormalities in the foot;
- No systemic conditions that may affect gait.

All experimental protocols were approved by a named institutional review committee. The subject was informed and consented to the test and publishing the results. All methods were carried out in accordance with relevant guidelines and regulations.

RESULTS AND DISCUSSIONS

Comparative Analysis of Plantar Pressure Distribution

Using the RSscan pressure plate and the associated system - Footscan 7 Gait, 2nd Generation, 0.5 Gait Scientific System, the dynamic pressures were measured for all 76 subjects, women and men. The sole of the foot was divided into 10 significant areas (Figure 1) and the distribution of the plantar pressure was obtained.



HL – Lateral heel
HM – Medial heel
MF – Middle foot
M1 – Metatarsal 1
M2 – Metatarsal 2
M3 – Metatarsal 3
M4 – Metatarsal 4
M5 – Metatarsal 5
T2-5 – Toes 2-5
T1 – Toe 1

Figure 1. Anatomical division of the plantar footprint

Following the classification of subjects, women and men, in the four groups: normal, high arched, flat and hallux valgus foot, resulted the average pressures on each area of the plantar surface, presented in the following Table 1.

Table 1: Mean plantar pressure values (N / cm^2) for each group: normal foot, flat foot, high arched foot, hallux-valgus foot

Foot			Toe 1	Toes 2-5	Metatarsal 1	Metatarsal 2	Metatarsal 3	Metatarsal 4	Metatarsal 5	Middle foot	Lateral heel	Medial heel
			Plantar pressure (N/cm^2)									
Normal	Women	Left	5	1.20	1.46	4.22	6.81	4.98	4	1.36	4.57	4.61
		Right	3.75	1.19	2.38	4.79	5.71	3.37	1.41	1.34	4.17	4.40
	Men	Left	3.31	0.96	2.82	6.48	8.44	6.56	3.54	0.66	7.36	6.36
		Right	3.6	3.18	0.98	5.54	6.84	4.3	2.4	1.8	6.68	5.76
High arched	Women	Left	3.51	1.57	2.75	5.18	7.31	3.52	2.60	1.37	5.88	5.05
		Right	3.62	0.82	2.02	5.41	5.74	2.74	1.37	0.83	4.55	4.62
	Men	Left	2.51	0.29	3.66	7.69	9.89	6.95	3.52	1.23	6.72	6.20
		Right	3.54	0.35	4.17	7.16	7.72	4.76	2.45	0.77	6.52	5.68
Flat	Women	Left	4	0.28	2.78	5.14	6.99	5.04	1.89	0.81	6.19	5.56
		Right	3.54	1.8	2.68	5.25	6.08	3.19	0.88	1.26	4.79	5.26
Hallux-Valgus	Men	Left	2.84	0.95	2.65	5.93	6.84	3.78	1.47	1.13	4.37	3.78
		Right	3.16	0.72	2.88	6.33	5.9	3.5	1.55	0.71	4.85	4.73

It can be seen from the previous table that there are no significant differences between the groups of subjects, the maximum pressure being recorded each time on the metatarsal 3, and the following, as values, on the metatarsal 2 and on the heel. Consequently, when designing the lower shoe assembly, the balance of plantar pressure distribution by the shape of the parts and the type of materials used must be taken into account.

Case Studies on Biomechanical Foot Analysis

From each category previously identified by applying the classification criteria based on plantar parameters (indices and angles), a representative subject was selected. For each case presented, the plantar pressures obtained on dynamics are analysed, following the next sequence: classification of the subject in the appropriate category, simultaneous visualisation of the footprint for the left and right foot, impulse analysis, recording the variation of plantar pressures and the forces exerted on the foot as a function of time, calculating the percentage values of balance on the rear-foot, heel and medial areas, positioning of the foot axis according to the direction of movement, identification of individual characteristics of walking phases and their temporal / spatial characterisation parameters, highlighting the hysteresis for heel and rear-foot areas, recommendations for the application of orthotic devices.

Subject S74 did not have health problems and did not have lower limb disorders (Figure 2a). According to the previous analysis, the presented subject is part of the category of those with normal foot. A brief analysis of plantar pressures will reveal deviations from the pattern of normal gait. Subject S57 (Figure 2b) has no health problems or lower limb disorders, but has lower back pain. Subject S65 (Figure 2c) does not present health problems. At the level of the foot, a structural anomaly of the flat foot type is identified. In case of prolonged physical exertion, the subject shows pain in the foot. Subject S26 (Figure 2d) has no health problems and has never had lower limb disorders. At a first investigation, there is a tendency of the big toe to deviate outwards, a situation associated with a structural anomaly of the hallux-valgus type.

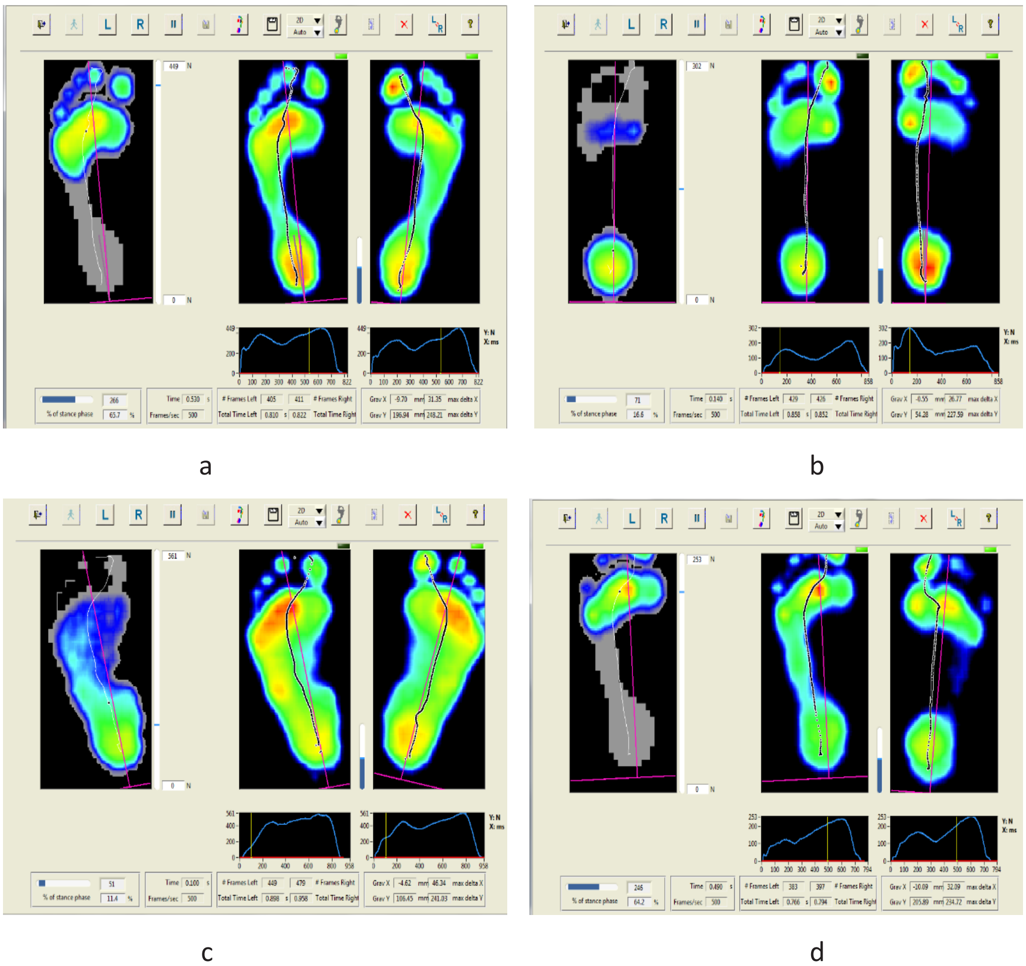


Figure 2. Simultaneous visualisation of the left and right foot and tracking the projection of the center of gravity (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

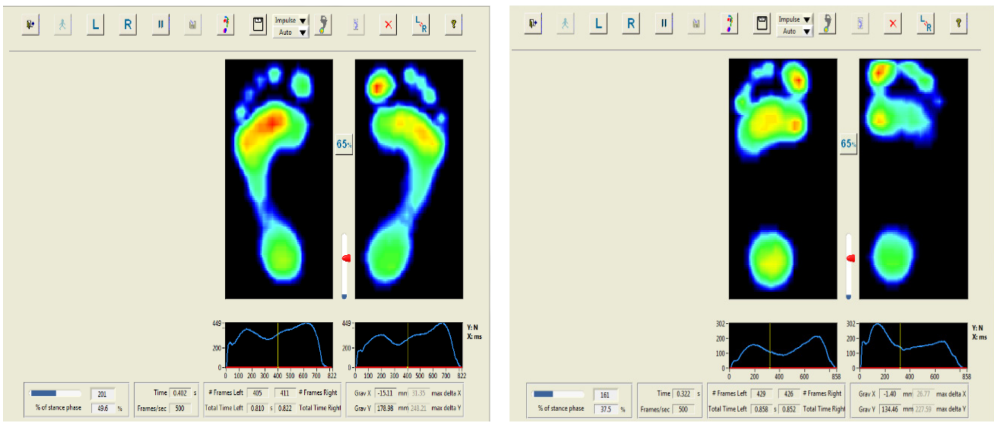
Figure 2a shows that there is a slight difference between the contact surfaces of both feet. Thus, in the middle area of the left foot, the contact area is smaller. The center of gravity displacement curve is lateral to the axis of symmetry of the foot, with a larger difference in the left foot. The highest-pressure points can be observed, on the left foot, in the area of the metatarsals 2-4, and on the right foot, under the thumb. Both the left and the right foot move at about the same speed, and as can be seen from the force graphs over time, the gait pattern for the two feet is similar.

The subject shown in Figure 2b has both feet strongly arched, the middle area does not make contact at all with the ground while walking. The displacement curve of the center of gravity is located inwards with respect to the longitudinal axis of the right foot. In the case of the left foot, it follows the axis of the foot until push off moment, when it changes direction inwards due to excessive loading of the toe 1. The highest-pressure points can be observed on the left foot in the area of the metatarsal 1 and toe 1, and on the right foot, under the metatarsal 1 and the big toe. The variation in strength as a function of time shows graphs that have different shapes for the right foot compared to the left one. If for the left foot, the shape of the curve approaches a shape specific to the normal gait pattern, for the right it is observed that in the first phases of gait (heel strike and mid-stance), the forces exerted on the heel area of the foot are much greater than those exercised on the rear-foot.

The footprint for the subject presented in Figure 2c suggests the flat foot. From the 2D view it can be seen that there is a slight difference between the contact surfaces of both feet, the contact surface being slightly smaller in the middle area of the left foot. The highest-pressure points can be observed on the heel area, on the medial-outer area of the foot, under the metatarsals 2-5 and under the toe 1.

In the case of the subject from Figure 2d, the middle area of the right foot does not come into contact with the support surface while walking, which indicates a high arched foot. The pronounced outward orientation of the toe 1 is also observed. The displacement curve of the center of gravity is lateral to the longitudinal axis of the foot. For the left foot it is positioned outside the longitudinal axis, and for the right foot it is located inwards. The highest-pressure points are observed on the left foot, in the area of the metatarsals 2-3, and on the right foot, under the big toe, the metatarsals 1-3 and in the area of the heel. Each foot has a movement close to the normal gait pattern.

Figure 3 shows the impulse exerted on the foot during the walking phases. Impulse is the product of force and time, measured in percentages. The longer the period of time in which a pressure is applied to a particular area, the greater the risk.



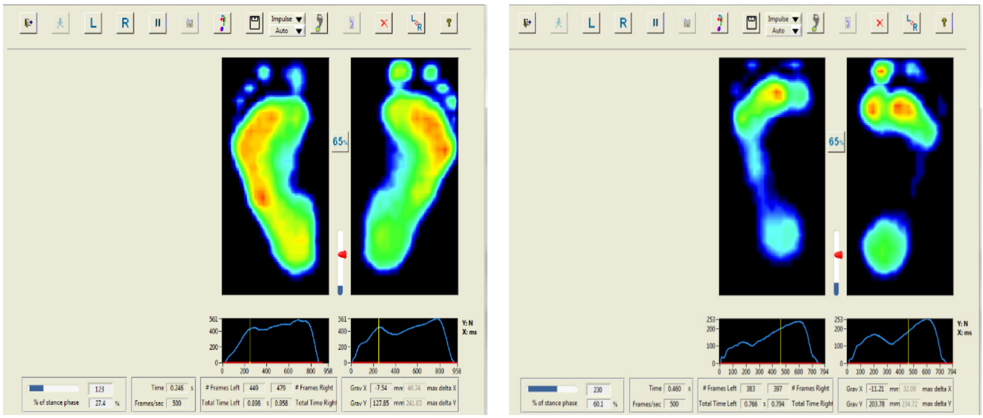


Figure 3. Impulse analysis (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

In the case of the subject presented in Figure 3a, the risk areas are the metatarsal 3 and the toe 1; while from Figure 3b, the risk areas are the metatarsal 1 and the toe 1; for the subject in Figure 3c, these are the metatarsals 2-5 and the lateral-medial area of the foot; the subject presented in Figure 3d shows high pressures in the area of the metatarsal 2, for the right foot and the toe 1, respectively, the metatarsals 1, 2 and 3 for the left foot.

If from the previous figure (Figure 3), the risk areas have been established based on the impulse, using Pressure / Time graphs presented in Figure 4 the values of the pressures for each area can be calculated exactly.

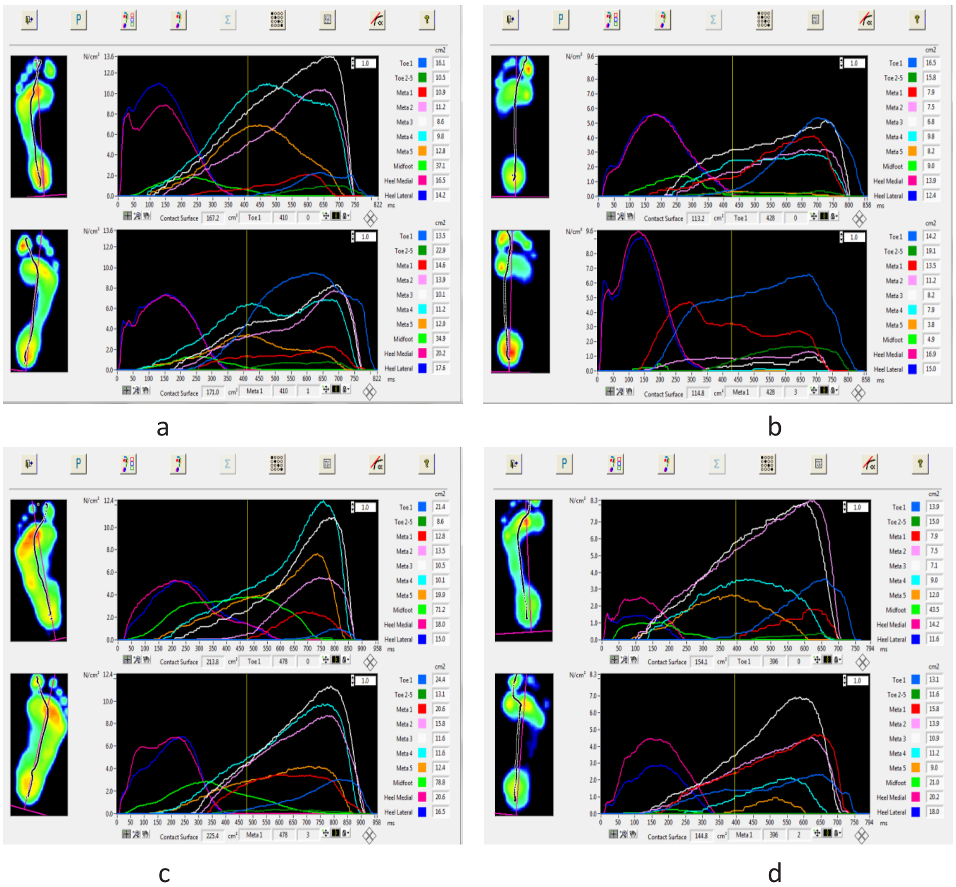


Figure 4. Variation of pressure as a function of time
(a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

The line of net force, the purple line, in Figure 5 represents the variation of the force as a function of time and it can be seen that it consists of the loads which appear in heel, medial and rear area of the foot and the times at which these loads occur.

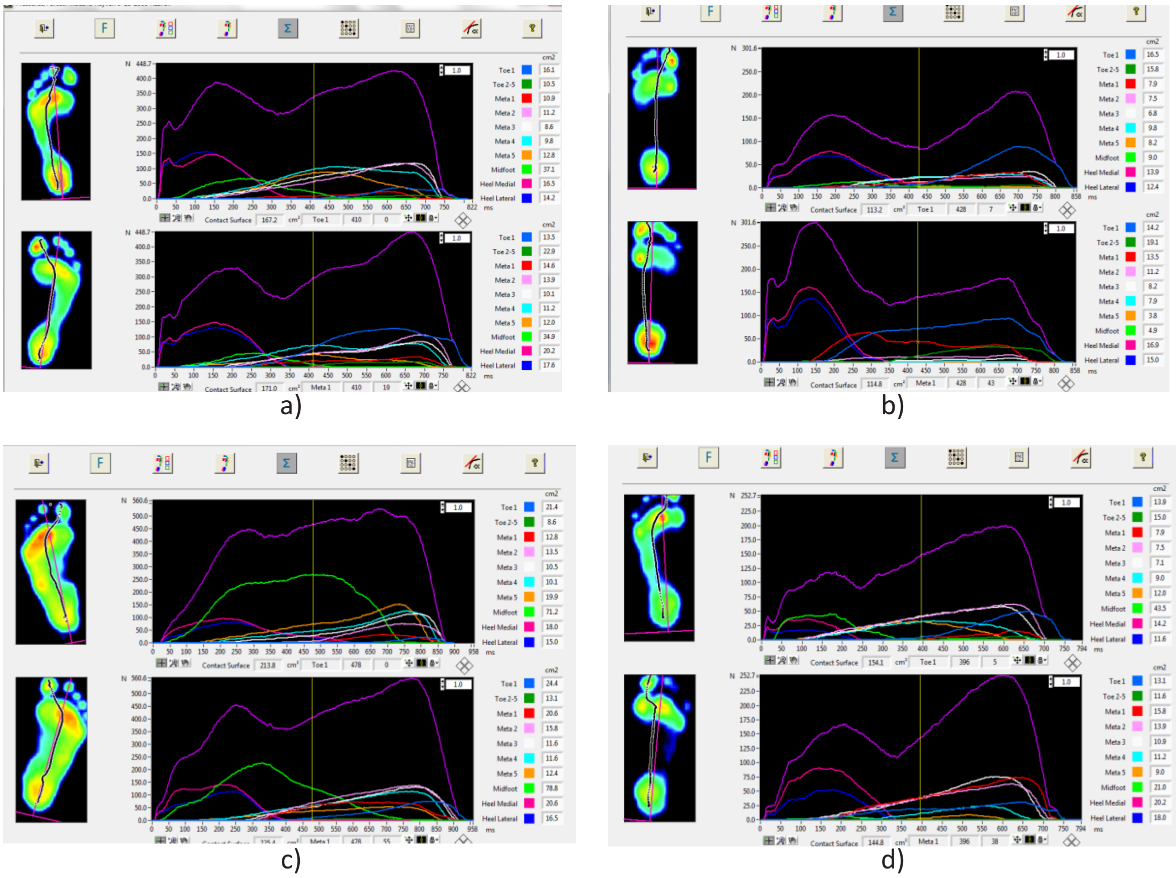
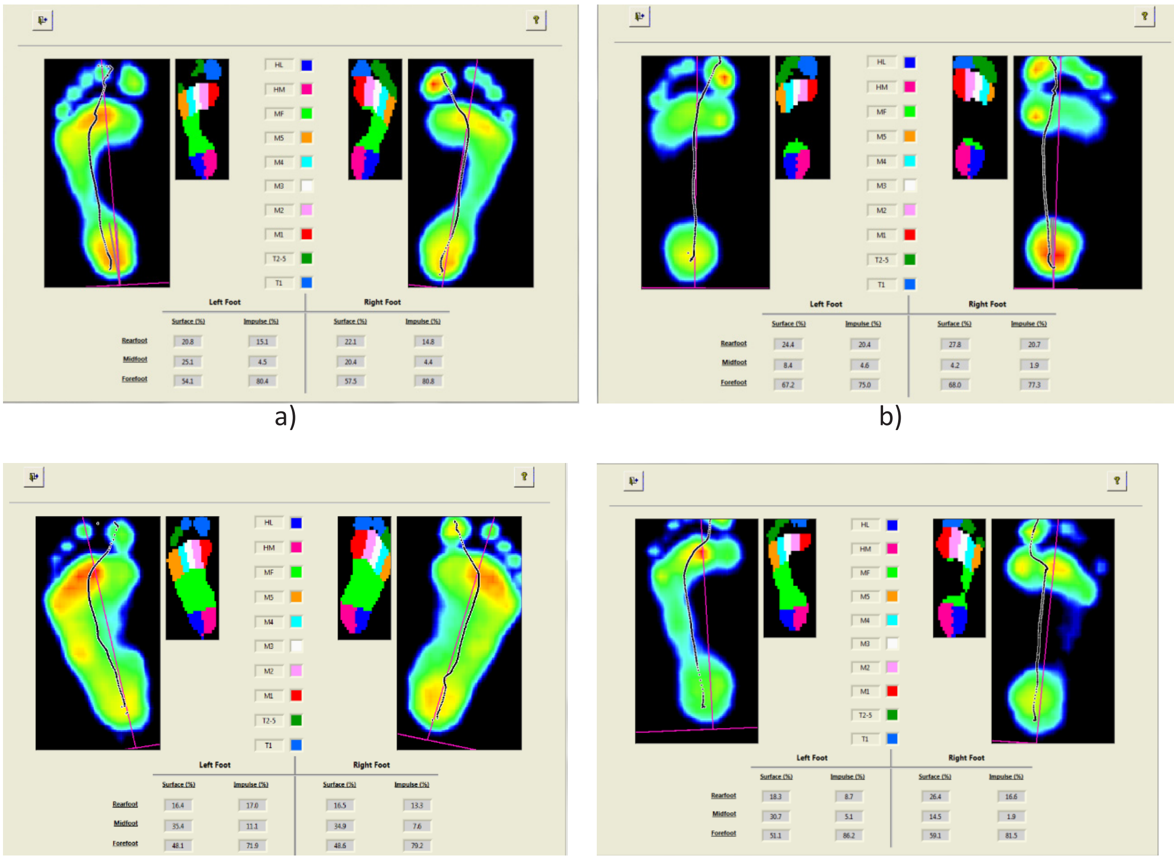


Figure 5. Variation of force as a function of time (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

For each of the four categories of foot studied, the walking patterns show that in the impact phases, both for the right foot and for the left foot, the pressures exerted by the foot in the heel area have values that would require the presence of additional elements in the shoe structure with shock damping role. For these subjects, the force-time curve does not have a normal shape due to high pressures under the heel and under the metatarsals, in the case of the left foot and the heel and toe 1, in the case of the right foot.

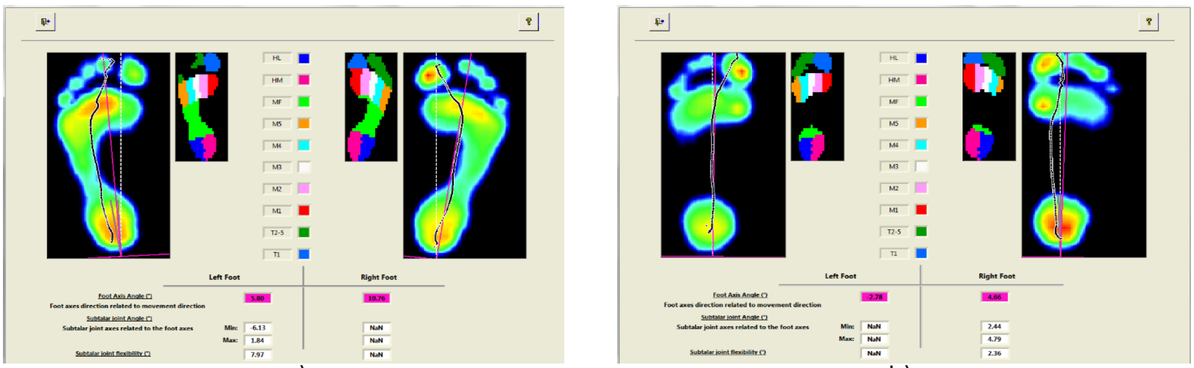
From Figure 6 can be observed the percentage values of the plantar surface corresponding to the heel, medial and rear-foot areas and the associated impulse. Based on these values, the category in which the foot is placed is automatically identified: normal (Figure 6a), flat (Figure 6b) or high arched (Figure 6c).



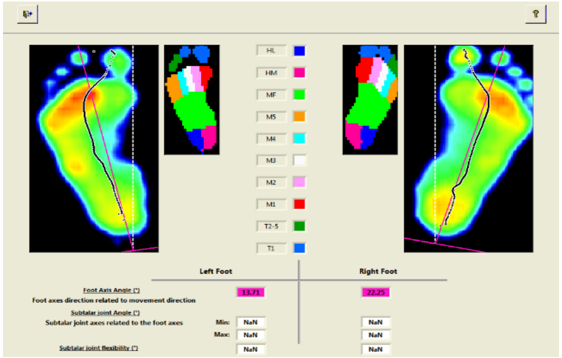
a) b) c) d)

Figure 6. Percentage value of rear-foot, medial and heel areas. Percentage value of the impulse (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

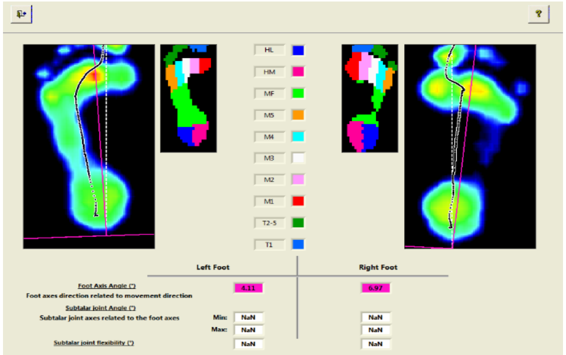
In Figure 7, the white line indicates the direction of movement, the pink line represents the longitudinal axis of the foot, and the black curve, following the movement of the point of gravity. The value of the angle formed between the direction of movement and the longitudinal axis of the foot indicates the abduction position of the foot if it has a positive sign, and the adduction position if it has a negative sign, respectively.



a) b)



c)

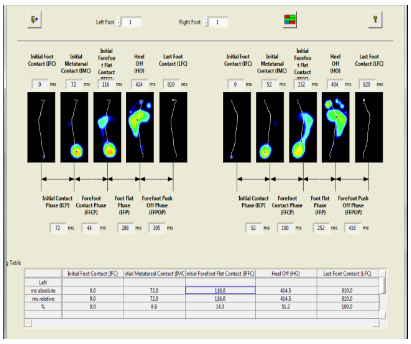


d)

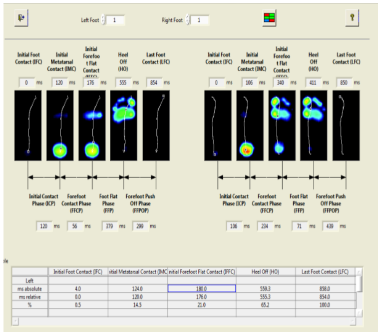
Figure 7. Foot axis direction and direction of movement
(a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

In the case of the subjects presented in Figures 7a, c, d, the right foot has an angle of abduction greater than the left foot.

In the Figure 8 the times to complete a step are shown.



a)



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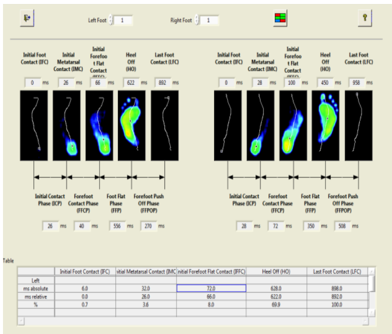

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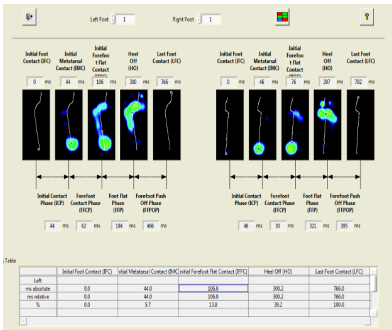


d)

Figure 8. Walking phases and time (ms) corresponding to each phase
(a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

For the subject with a normal foot, Figure 8a, it can be seen that the time required for the left foot to complete a step is 10 ms less than that for the right foot (810 and 820 ms, respectively). Even if the right foot needs only 52 ms for the initial contact, compared to 72 ms in the case of the left foot, the push off phase is longer on this foot, thus explaining the high pressure on the toes.

In the case of the high arched foot, Figure 8b, the time required for the left foot to complete a step is 4 ms longer than that for the right foot (854, respectively 850), even if these values are very close, in areas they differ very much, the right foot needs 120 ms for the initial contact, compared to 106 ms for the left foot; 56 ms for metatarsal area contact on the left foot and 234 ms on the right foot; 379 ms for mid-stance on the entire plantar surface for the left foot and 71 ms for the right foot and the push off phase is longer on the right foot, 439 ms compared to 299 ms for the left foot, thus explaining the high pressure on the toes, in this case, the toe 1.

Regarding the flat foot, Figure 8c, it can be seen that the time required for the left foot to complete a step is 66 ms less than that for the right foot (892 and 958 respectively), in some areas the values differ greatly, the right foot needs 28 ms for the initial contact, compared to 26 ms for the left foot; 40 ms for medial area contact on the left foot and 72 ms on the right foot; 556 ms for mid-stance on the entire plantar surface for the left foot and 350 ms for the right foot; the push off phase is longer on the right foot, 508 ms compared to 270 ms for the left foot, thus explaining the high pressure on the toe area, in this case, the toe 1.

For the subject with the hallux-valgus anomaly, Figure 8d, it can be seen that the time required for the left foot to complete a step is 26 ms less than that for the right foot (766, respectively 792), in some areas the values differ greatly, the right foot needs 44 ms for the initial contact, compared to 46 ms for the left foot; 62 ms for medial area contact on the left foot and 30 ms on the right foot; 194 ms for mid-stance on the entire plantar surface for the left foot and 321 ms for the right foot; the push off phase is longer on the left foot, 466 ms compared to 395 ms for the right foot, thus explaining the high pressure on the toes.

In all analysed cases, the balance graph for the heel movement shows that the left foot is loaded less than the average in the mid-stance phase, suggesting a possible supination of the heel (Figure 9).

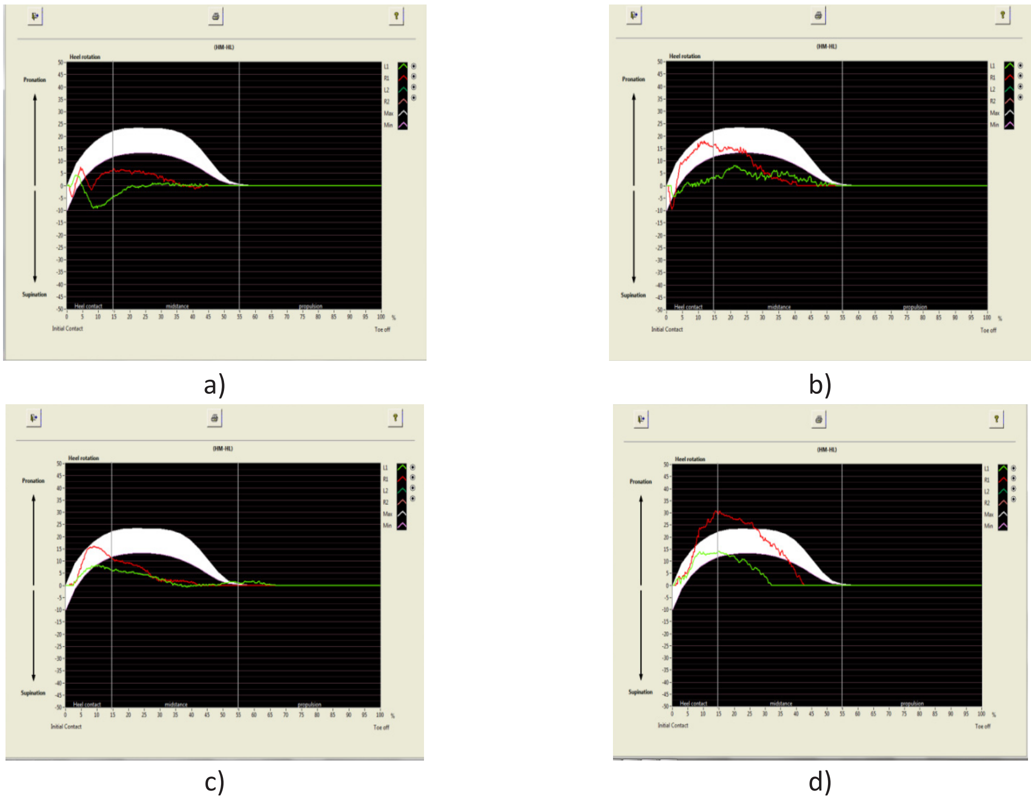
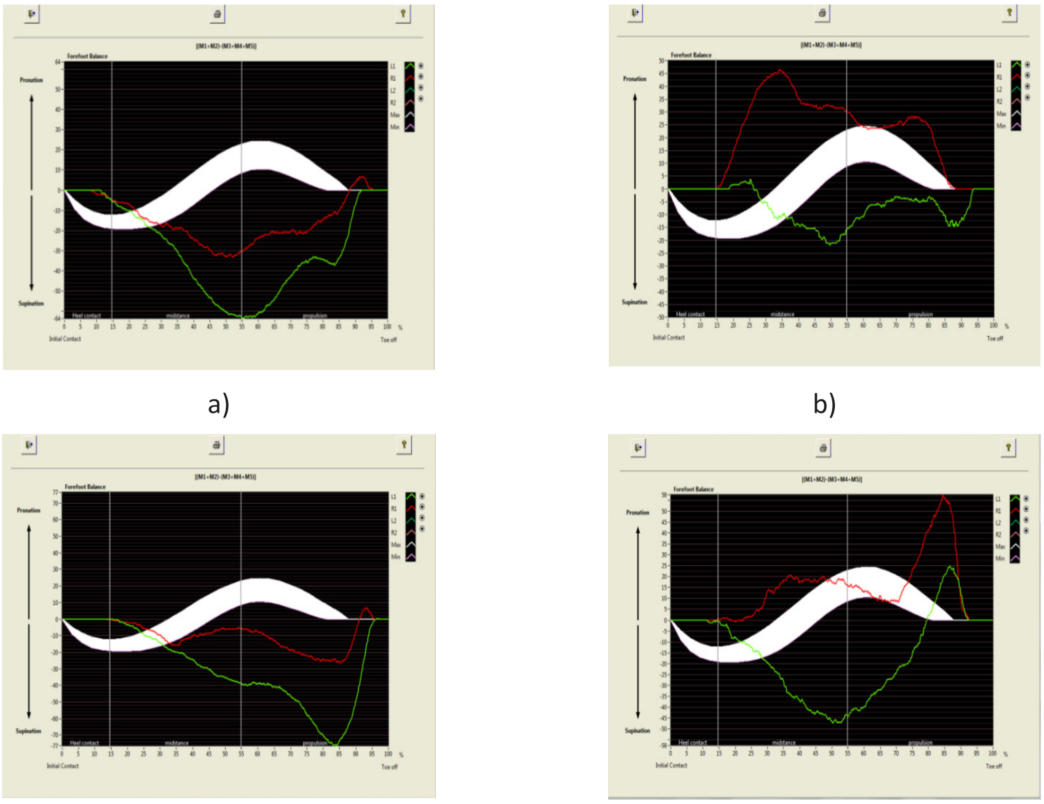


Figure 9. Heel hysteresis (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

For subjects with normal, high arched, and flat feet, the balance graph for the rear-foot area shows that both feet (left and right) are loaded less than normal in the mid-stance phase on the entire plantar surface, thus suggesting a possible supination of them (Figures 10 a, b, c).

For the hallux-valgus foot, Figure 10d, the balance graph for the rear-foot area shows that the right is loaded more than normal in the mid-stance phase on the entire plantar surface, thus suggesting a possible pronation of it, and the left is loaded less than normal values, in the phase of mid-stance, suggesting supination in that area. Towards the push off phase, the loads increase due to the high pressure that is exerted on the toe 1.



a) b) c) d)

Figure 10. Rear-foot hysteresis (a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

Taking into account the contact areas of the foot while walking, the value of the impulse in those areas and the calculations made to obtain equilibrium graphs, orthotic devices may be recommended (Figure 11).

For the normal foot, the recommendation is to lift the left foot outward to prevent supination. With regard to the high arched foot, it is recommended to use a custom orthosis on the inside of the hollow area, especially on the right foot, being more severely affected. In the case of the flat foot, it is suggested to insert the orthoses in the heel area for both feet and in the outer part of the middle area of the left foot. For the foot with hallux-valgus, the recommendation is an orthosis in the heel area but also for the release of the metatarsal areas 1-3.

a) b) c) d)

Figure 11. Areas of application of orthotic devices
(a-normal foot, b-high arched foot, c-flat foot, d-hallux-valgus foot)

CONCLUSIONS

In the stage of modelling and designing the component parts of the bottom assembly of footwear (insole, sole), it is necessary to consider balancing the distribution of plantar pressures by the shape of the component parts and by the type of materials used. The analysis of the distribution of plantar pressures on the surface of the sole of the foot showed for both categories of subjects, women and men, the presence of pressure peaks under the metatarsals 2 and 3 and in the heels. These areas were considered risk areas, and in the modelling and design of the bottom assembly, solutions were proposed to balance the pressures on the plantar surface by choosing the appropriate dimensional and shape characteristics of the components of this assembly.

For the biomechanics studies within this research, the RSScan plantar pressure recording system was used. Modern computer-aided equipment, assisted by specialised recording, measurement and analysis software, offers multiple advantages in terms of the possibility of integrating information obtained from simple analysis of plantar footprint configuration with exact values of plantar pressures and forces exerted on foot, in static and dynamic.

A direction for further research initiated in this article is the design of models to validate the results recorded for each of the analysis steps mentioned above through simulation models and techniques. Currently, through specialized studies undertaken by various research teams, it has been possible to simulate on simple models of the foot and validate the pressures and forces recorded on the plantar surface in a position of bilateral orthostatic support. The simulation of dynamic conditions and the validation of other parameters for characterizing gait is a topic for future studies, this paper initiating new research directions in this regard.

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EUROPEAN RESEARCH AREA

COTANCE NEWSLETTERS

Starting with January 2019, the COTANCE Council will issue a monthly ***COTANCE Newsletter*** with the purpose of **promoting an improved image of leather** to relevant decision makers and domestic stakeholders including Members of the European and National Parliament, Governmental authorities, Ministerial officers, Customers of the leather industry, Brands, Retail chains, Relevant NGOs, Designers, etc. The monthly newsletters present topics that tell the truth about a controversial aspect or a fact that is not well known by the general public to bring about a better understanding of leather and the European leather industry, as well as a positive predisposition to legislate in favor of the leather industry. The newsletters are available in seven languages at https://www.euroleather.com/index.php/newsletter, and were also published in the 2019-2021 issues of *Leather and Footwear Journal*. Newsletters 8-10 are given below.

NEWS 8/2021

Leather Goes for Zero Allocation

The leather industry has long argued that as a by-product, our raw materials, hides and skins, should not carry any environmental burden from the rearing of livestock. This is the concept of zero allocation.

What is at stake with zero allocation? There is a debate when determining the carbon footprint of animal by-products. Two sides oppose each other.

One side, which includes slaughterhouses, is convinced that the carbon emissions caused by a cow during its lifetime must be distributed among meat and milk and also all by-products.

For hides, this results in a carbon dioxide (CO_2) burden derived from agriculture, which is added to leather. This gives a disadvantage to animal by-products compared to, for example, synthetic products.

The other side, including the tanners, stands for zero allocation. This means that only the products that the animal was reared for, i.e. meat and milk, should carry the CO_2 burden from animal husbandry. Unlike the primary products of livestock rearing, meat and milk, by-products like hides and skins may not always be further processed (e.g. because the carbon footprint is too large), and become waste. In the 2008 and 2020 crises, this happened with a large number of hides and skins.

If the skins available worldwide were disposed of to landfill, their decomposition would create significant additional CO_2, amounting to approximately 5 million tons of harmful climate gases.

According to the US EPA emissions equivalencies calculator, that corresponds to the annual emissions of 1,087,400 average cars.

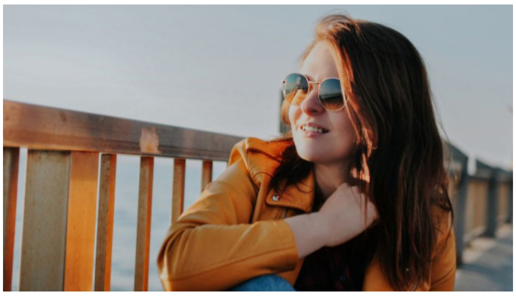
That's quite a saving! Don't waste this resource, use it!

edited by COTANCE

in collaboration with VDL Verband der Deutschen Lederindustrie e.V.

NEWS 9/2021

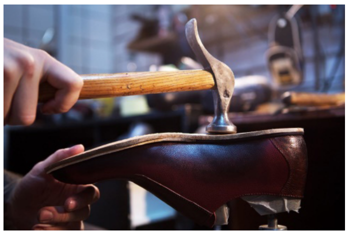
Leather: The Best of Many Worlds!



The way we look at materials has changed very significantly. When primitive man discovered that animal hides could protect him from harsh weather, leather was just a *thing* that was available and useful. Now it's a *material*. However it is a material of excellence, combining the best of many worlds in a unique way!

The best in a world of heritage

Always present alongside mankind, leather evolved from a simple layer of clothing and protection to become an element of culture in totems and amulets, musical instruments, sheets of parchment or book covers, a material that could embellish the most diverse handicrafts. It's hard to find a culture that has not integrated leather in its traditions.



The best in a world of durability

Leather is an example of endurance. Leather articles can be maintained and repaired extending their useful life. Lasting a lifetime, they may be passed on to the next generations. Indeed, in the world of materials, there is nothing more beautiful than aged leather.

The best in a world of sustainability

Today more than ever, it is essential to ensure sustainability.

Tanners recover hides and skins as a residue from the food industry and recycle them into leather so that they do not pile up as waste. Unlike fossil fuels, the feedstock for leather is renewable.

In addition, thanks to modern technology, leather has offset the negative impacts of its complex production process; cleaning wastewater and turning solid waste into useful goods, such as fertilizers, tallow or glue. A perfect example of circular economy.

The best in a world of fashion and design

In the past leather was only available in limited shades and textures. Today it is like a chameleon, thanks to the multiple aspects it can take. Designers and fashion lovers can find leather in any color, with any desired hardness or softness, thick or thin, glossy or matt… There are no limits to creativity.

The best in a world of performance

Leather is also known for its outstanding and unique physical properties.

Breathable and comfortable, resistant to tear and stretch, as well as to sunlight and water, this biomaterial boasts physical, chemical and fastness performances that are unmatched by the alternatives.

Look at it from any angle, leather is the best of many worlds!
Enjoy leather! Good for you, good for the planet.

edited by

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leather from portugal

NEWS 10/2021

Leather: A Gift of Nature!

According to FAO data, there are around 1,600 million cattle, 1,150 million sheep and 1,000 million goats in the world.

The reasons for keeping animals are manifold and range from raising them for dairy and meat, to using them as a source of social prestige, assets, power or a convenient means of transport.

Livestock convert grass and leaves that can't be assimilated by humans into highly nutritious food. In the EU nearly 50% of their fodder is provided by grassland; the rest is constituted by feed coming from fodder crops, crop residues, oil seed cakes, by-products and about 13% of grains.

Livestock keeps our pastureland and its biodiversity in good shape.

Where livestock is farmed, animal welfare standards are essential and the EU Animal Welfare Policy includes the "Five Freedoms for the Welfare of Farmed Animals".

Animal welfare is an ethical duty. An obligation that only has advantages; only well-groomed and healthy animals produce quality milk and, at the end of their lives, a tasty meat. Moreover, only well treated animals enjoy a healthy hide or skin, which tanners can then process into beautiful leather.

Conversely, a lack of or poor animal welfare has only adverse consequences. There is, of course, animal suffering, but also farmers enduring losses, and, at the end of the chain, a tanner who doesn't get a quality feedstock. Animal diseases, parasitic attacks, injuries or skin allergies are all revealed when hides/skins are transformed into leather.

Tanners can read hides and skins like in an open book. They can identify the way the animal has been treated during life and whether the slaughter and the flaying has been performed professionally. The less defects they find, the better the animals have been treated.

A good quality hide/skin yields a good quality leather. Where possible, European tanners pick and choose only the best. They invest time, resources and efforts in transparency and traceability so as to feed the information on defects back into their upstream supply chains and help continuously improve the quality through better animal welfare.

More quality leather means a more sustainable value chain; less waste, better ethics and more prosperity for everybody!

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