IMPROVING THE FOOTWEAR ERGONOMICS BY PERSONALIZING ITS SHAPE

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The paper examines the possibility and relevance of developing and manufacturing comfortable ergonomic shoes with individual anthropometric insoles in the context of a standard footwear enterprise. The comfortableness of the shoes is achieved due to the correct anthropometrically justified shape of the last and the load-relieving anatomical insole-sole. All initial information for designing is obtained by 3D scanning of a customer's foot and its imprint on polyurethane foam on a specialized professional 3D scanner. Designing of the last is carried out in LastMaker and PowerShape software environment while designing of the insole is performed in PowerShape based on the configuration of the lower surface of the designed last, which corresponds to the relief of the plantar surface of the foot. The anatomical insole was manufactured by milling on a 3-ways CNC machine. The general process of manufacturing shoes complies with the standard technology approved at the manufacturing facility. The individuality of the shoe shape is achieved due to the individually designed shoe last and anatomical insole. Experimental wear showed that shoes produced in this way meet comfortableness requirements to a greater extent than those manufactured using standard lasts and components. The proposed shape of the insole facilitates even distribution of body weight over the entire surface of the foot sole. When walking, such an insole ensures proper functioning of all parts of the foot at each stage of a step. The goal of improving the ergonomicity and sustainability of the shoes being developed is also achieved with the help of a special upper design that combines the insole-lining and upper elements, which reduces the number of shoe components and the technological process for its manufacture.

Keywords: footwear last, 3D design, foot parameters

INTRODUCTION

The new progressive fashion stands out due to its focus on human health and comfort. However, there are still many unresolved issues in the development and manufacturing of ergonomic footwear. The number of foot diseases causes great concern among European and American specialists. Many of these diseases, such as valgus deformity, flat feet, heel spurs, etc., are acquired and can be caused by uncomfortable, poorly fitted shoes.

Thus, the main problem of today's shoe industry is the large number of low-quality shoes worn by people. The survey indicated that from 46 to 81% of participants wear shoes that are too tight because they are literally unable to choose shoes with the suitable fullness from the available range (Buldt *et al*., 2018).

Recent questionnaires and surveys (Chertenko *et al*., 2022) have shown a large number of problems with the comfortableness of women's shoes presented in the mass market.

Ergonomicity and comfortableness of shoes are often sacrificed for the sake of achieving aesthetics as the main factor of competitiveness. After all, it is no secret that buyers, who shape the assortment of fashion stores or boutiques, often ignore the requirements for the ergonomicity of shoes. Thus, ultimately, consumers are forced to wear shoes that cause discomfort or even pain and disruption of movement biomechanics.

However, the current global trend of sustainable fashion is focused on the maximum ergonomicity of products used by people. Therefore, today, due to the shift of the fashion vector towards consumer needs, we have a chance to combine ergonomicity and aesthetics. Another trend of current global fashion involves personalization and customization of products according to the needs of a specific consumer.

Therefore, the major goal of the paper was the development of a convenient shape and ergonomic design of shoes, which is able to ensure the normal functioning of the

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human foot, comfortable wear and an attractive look of shoes. At the same time, we set the goal of individualizing the shape in the context of serial shoe production.

We assume that the ergonomicity and comfortableness of shoes can be enhanced by the manufacture of anatomical insoles that match the shape of a foot, as well as by improving the shape of a last. However, the new advanced ergonomic last shape and ergonomic insoles must meet certain practical requirements, they must be easy to use and require little physical effort in their production and use. Otherwise, the modifications are unlikely to be accepted voluntarily and supported in the long run (Yardley *et al*., 2008).

As a rule, shoes consist of a number of components, each of which can affect walking mechanics (Menant *et al*., 2008). Shoes with milled individual or ergonomic insoles can be both closed-toe (loafers, sneakers, running shoes, boots, ankle boots, shoes, moccasins, etc.) and open (strap shoes, mules, clogs, etc.).

In a significant number of people, certain foot pathologies are caused by inappropriate shoe shape, size, overall anthropometric data that do not correspond to the specific population group (Deselnicu *et al*., 2016). A human foot not only plays an important role in support and movement, but can also affect a person's lifestyle. Decreasing the comfortableness of shoe sizes is the major cause of discomfort, pain, calluses, valgus deformity, ulcers, etc. Accidents and foot diseases lead to a decrease in mobility, which results in the exacerbation of other diseases.

The most important component in the production of shoes is a shoe last. This is the three-dimensional shape of the foot that is used to create shoes. The shape and size of a foot, comfortableness parameters, fashion and design type of shoes affect their manufacturing (Sarghie *et al*., 2013).

Traditionally, shoes are classified based on length and width (balls' circumference). But in addition to the length, girth and shape of the feet, the sole surfaces of human feet can also differ. Walking with completely flat insoles can cause improper load on the feet muscles. Parameters such as axial angle, Hallux-Valgus angle, distribution of body weight on each foot are important for the mechanics of walking. These data for the two feet of the same person may differ (Costea *et al*., 2014). Anatomic insoles are, in fact, used to ensure the correct load on one's feet, as well as for the even distribution of weight between both limbs. For collecting information about a human foot, the most advanced and accurate technique is foot 3D scanning.

Profiled increased-comfort insoles are removable (insertable) and fixed. The shape of the designed last will depend on the type of insole. When using a fixed insole, the relief of the lower surface of a last corresponds to the relief of the upper surface of the insole. This relief depends on the purpose of the shoes and on the anatomical features of a foot. While manufacturing mass-produced shoes, the relief of the insole has averaged parameters. Shoes with such insoles are produced by companies like Birkenstock, Orteks, Walkx, etc. These insoles have won the favor of many consumers due to the increased comfortableness of the manufactured shoes.

The top surface of the insole corresponds to the shape of the foot sole, the side protrusions of the insole (from 5 to 20 mm high) are located on the side surface of the shoe. In the instep part, there is always a hard instep support. A heel socket with a depth of at least 6 mm is placed in the heel part. The arch support of the longitudinal arch of the foot is provided by pad thickness 8-15 mm (Fainberh and Husev, 1984). To support the transverse arch of the foot, a metatarsal pad (Seitz roller) with a height of 2 to 4 mm can be used.

MATERIALS AND METHODS

All the initial information necessary for designing the shape of the last and the anatomical insole was obtained using 3D scanning (Fig.1). We used a Scanner Foot in

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3D with a working scanning area of 400x180x180 mm and a scanning accuracy of 1.3 mm. The data obtained during scanning can be used to estimate the foot health, analyze the morphological and statistical dimensions of the foot, for the footwear design, the selection of shoes and insoles in shoe stores or orthopedic salons (Kimura *et al*., 2012).

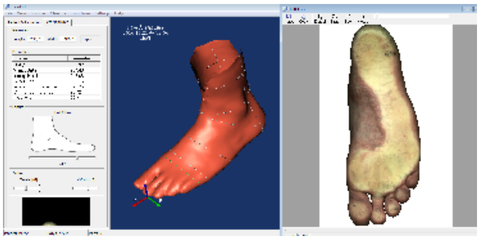


Figure 1. The results of the foot 3D scanning

Information obtained by 3D scanning of foot prints on special foam was also used to design the shape of the insoles (Fig. 2 a). The paper experimentally proved the possibility of obtaining a digital 3D shape of the plantar surface of the foot without the use of plaster casting. One foam block with a foot print was scanned on the Foot In3D scanner (Fig. 2b), so we don't need to perform additional procedures for making a plaster positive.

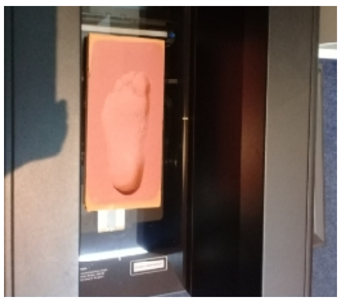
 a  b

Figure 2. Obtaining a footprint using polyurethane foam

The results of foot scanning according to the standard procedure on a 3D scanner and scanning of polymer foam with a foot imprint demonstrated the need to use a polymer foam that perfectly reproduces the relief of the foot due to the uniform compression of the soft tissues of the foot. As the results of the comparison of 3D models showed, scanning the foot on the scanner does not provide such detailed information as the reflection on the polymer foam (Fig. 3).

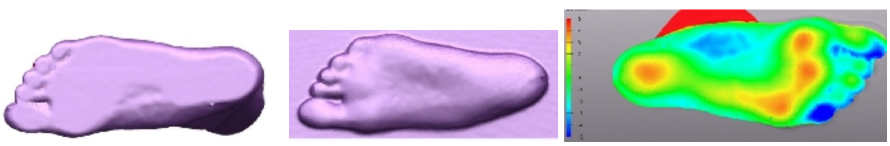


Figure 3. Comparison of the 3D model of a foot imprint on the foam and the foot scanned on a 3D scanner

The results showed significant deviations in the relief of the plantar surface, especially in the ball area and heel area (up to 4 mm).

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RESULTS AND DISCUSSION

The main process of designing lasts and insoles based on the received data took place in the 3D PowerShape environment (Fig. 4). According to the 3D shape of the customer's foot, an ergonomic model of the last was developed, as well as a supporting anatomical sole, wich commons an insole and outsole. In order to increase the comfort of the footwear, the ball girth was increased, the toe part was slightly expanded in accordance with the recommendations of the orthopedic doctor, taking into account the features of the normal biomechanics of the foot during movement.

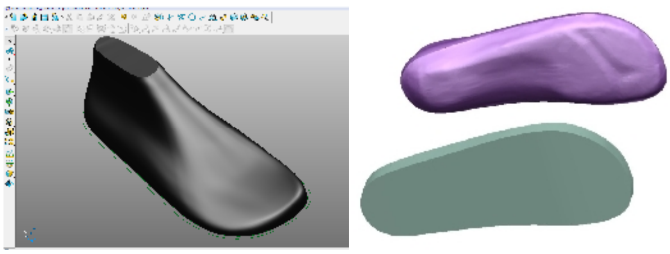

Figure 4. The designed shoe last and insole (Power Shape 3D software)

Preparation for the manufacture of designed anatomical sole took place in the ArtCAM software, which allows you to develop the processing trajectory and set the 3D processing parameters for the CNC milling (Fig. 5a). After that that sole was made using a standard 3-ways CNC machine from EVA material (Fig. 5b). Sheets of EVA-pores with a thickness of 10 mm were pre-glued in two layers, and in the areas of increased thickness (the area supporting the internal arch) a third layer was added.

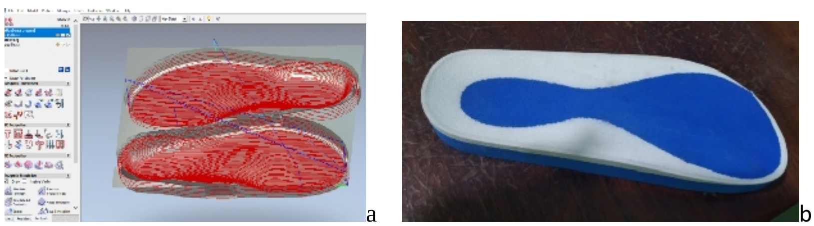

Figure 5. The main stages of insole modeling in ArtCAM

A collection of ergonomic women's shoes, consisting of three models of summer open sandals with anatomical insoles, was offered to the customer based on the developed individual shape of the last (Fig. 6).

Figure 6. A collection of summer women's shoes with an anatomical sole

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A sample of sandals was made at the shoe factory. The upper part of the shoe (straps) has a structural unity with the insole-lining (Fig. 7).

Figure 7. Sandals pattern and sandals on the last

The upper part of that construction is more comfortable, because the number of seams that can rub the foot is reduced. Also this model uses natural materials (cattle skin), which is an ecological material with high hygienic properties (moisture permeability and breathability, durability). The lacing allows you to adjust the width, which eliminates the possibility of discomfort when wearing shoes that are too narrow in the instep and ball area. The upper part has design supported and fixed the instep part of the foot. The test wearing of the shoe sample confirmed the comfort of the form.

To compare the sensations, the customer was offered to wear standard models of shoes manufactured at the factory. Two models of standart sandals with different sole shapes and also the developed personal sandal with anatomic sole were selected for test.

I II III

Figure 8. The tested models of the sandals: model I, model II and model III

The customer alternately wore three pairs of shoes from Fig. 8 for one day for 7-8 hours each. It was suggested to evaluate the feeling of comfort while wearing according to the questionnaire. The maximum score (10) was assigned to the most comfortable shoes, the minimum score (1) to the least comfortable. The results of test are shown on Fig. 9.

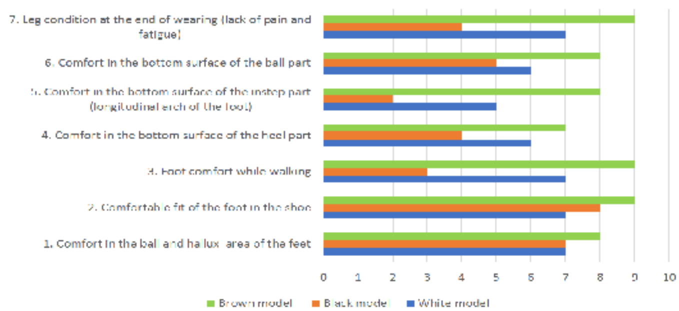

Figure 9. Comparing the comfort rating of the personal ergonomic shoes and the standard shoe

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Such an increase in subjective comfort index can be explained in terms of foot anatomy and movement biomechanics. The fact is that the proposed shape of the insole, designed on the basis of the plantar relief of the foot, taking into account the recommendations of an orthopedist, facilitates even distribution of body weight over the entire surface of the foot, which significantly reduces the load on the heel and other areas of peak pressure. When walking, such an insole ensures proper functioning of all parts of the foot at each stage of a step. As a result, the general feeling of tiredness in the foot and lower leg is significantly reduced.

CONCLUSIONS

The shoes developed in this work were designed based on the 3D shape of a foot using advanced computer technologies and equipment. Test wear demonstrated a high degree of comfortableness of such shoes for the customer. At the same time, there has been suggested an original design of the upper of the shoe made according to the principle of moccasins, when the insole and the elements of the upper comprise a single part, which reduces the number of operations for assembling the uppers of the shoe, as well as the amount of excess material that is usually spent on the lasting edge. The anatomical insole also performs the function of the sole, and, therefore, it eliminates the need for the use of additional parts and the process of assembling them, which also significantly increases the value of the proposed shoe design from the perspective of sustainability. However, the design of the upper of the developed sandals needs to be improved from an aesthetic point of view, as well as from the perspective of the rationality of the templates' shape in order to promote a more economical use of genuine leather from which the upper of the shoes is made. In addition, in the future, we are planning to investigate the possibility of utilizing a single averaged shape of the last for individual anatomical insoles with different configurations.

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