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Design of a 3D Adaptive Regeneration Model for Sports Soles

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Abstract
Comfortable wearing and fashionable appearance are the purpose of sports shoe design. The comfort, lightweight, shock absorption and other functional design of sports shoes involve multidisciplinary comprehensive knowledge, and the sole structure is mostly composed of irregular complex surfaces, which is difficult to design as well as time-consuming and labor-consuming for repeated modeling. Therefore, it is necessary to adopt advanced science and technology to continuously explore and improve the structural design method of sports shoes. This paper presents a new method to create a regeneration parameterized sole model based on the layered parameterization of the foot shape. The method combines the principle of ergonomics to complete the layered solid modeling of the sole structure, parametrically control the variables of the model, construct the parametric model, and realize the design of the parametric adaptive regeneration model; Through the digital virtual assembly design method, the interactive digital assembly design of the three parts of the sole structure, including the outsole, midsole and insole, is realized based on the foot shape, and the problem of the fitness between the sports sole structures is solved. The research results provide a complete digital and flexible design method and evaluation strategy for the structural design of a sports sole, reduce the designer's repeated modeling pressure on complex sole models, effectively shorten the research and development cycle of sports shoes, and provide a self-adaptive and regenerative basic model for the optimization design of sports sole structural mechanics.

Keywords
sports sole, parametric design, regeneration model, virtual assembly.

1. Introduction

Sports shoes have the characteristics of a soft and breathable upper and light elastic sole. They are essential for daily life, sports exercise and sports competition. In recent years, people's demand for high-quality performance, such as appearance, comfort, shock absorption, lightweight and personalized design of sports shoes has gradually increased [1]. Therefore, the continuous optimization of the structural design of sports shoes and the exploration of new materials are the hot issues in the current footwear field.

The structure of a sports sole is closely related to foot shape, and its structural performance directly affects the comfort of wearing. Therefore, it is particularly important to realize personalized and flexible design according to different foot shapes. The diversity of foot morphology leads to a wide variety of sole structures, and the modeling process of a sole model is complex and cumbersome, which consumes a lot of time and energy of designers. With the application of computer-aided digital technology [2, 3] in the field of design becoming more and more mature, three-dimensional parametric design technology are widely used in mechanical equipment, automobile, aerospace, industrial products, biotechnology and other fields [4-6].

In the field of footwear design, many scholars have also used computer-aided design and parametric technology to explore the design of sports shoes in many aspects. Pan Junyuan and Wang Jun studied the parametric customization of digital shoe last [7]. Pan Meili, Wu Xiaohui et al. studied the application of methods such as parametric constraint definition of sole contour [8, 9]. Luo Guanghan and Davia-Aracil et al. used 2d/3d software to conduct 3D complex modeling and parametric sketching of the sole, and quickly realized the sketch drawing of the sole contour curve [10-11]. Zhang Yachuan et al. used Rhino software to parameterize the design of sports shoe soles [12].

The current research case discusses the parametric application of computer three-dimensional digital technology in a part of the sole contour, grain distribution and other aspects from multiple angles; but there is no clear method to use computer-aided design and parametric technology to realize the parametric design of the overall structure of a complex sports sole and change the parameter value to achieve the rapid generation of a new model of the complex sole. At present, most of the main modeling methods are for recreating new models for new styles, which will consume a lot of time and energy for designers. To solve these problems, this paper proposes a new method to create a 3D model of a sole based on the layered parameterization of the foot shape. In this method, 3D design software Creo Parametric® was used to complete a layered modeling of the complex structure of the sports sole, and ta parametric model was constructed by controlling the model parameter variables and setting the relationship between the dimensions, so as to realize the design of a parametric adaptive regeneration model. This method can reduce the repeated modeling burden of designers, shorten the research and development cycle, and provide a new way for the comfort, lightweight and efficient personalized design of sports shoes.

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2. Analysis of sports sole design

The shape of a sports sole is composed of irregular complex surfaces, which can be divided into three main parts: midsole, outsole and insole [13]. The midsole is located between the insole and the outsole and is composed of various foam shaped materials. The research and development of high-end sports shoes by major enterprises is mainly in the midsole, which determines the overall mechanical properties of the sole and is the core part of the optimal design. According to the theories of material physics, structural physics and biomechanics, technology research and development are carried out from the aspects of cushioning materials, cushioning structures and stable structures, so as to improve the performance of shoes, such as protection, cushioning, shock absorption and comfort. The outsole belongs to the contact surface between the shoe and the ground, and its core performance requirements are reflected in skid resistance, wear resistance, and grip. The insole is located above the midsole and is in direct contact with plantar, where the focus is on the optimization design of softness, springback and breathability. The reasonable design of the midsole, outsole and insole of the sports sole determines the comfort.

Due to the different foot types and the diversity of sports' needs, there are many kinds of sports sole designs, such as sport type, leisure type, special foot type, and so on. Therefore, the design and modeling of a sports sole consumes a lot of time and energy, and the design of the fitness of the sports sole structure and foot shape is also particularly important. In order to solve these problems, we need to improve the comfort and efficiency of sports shoes. Combined with the principle of ergonomics, we constructed a design idea for three-dimensional parametric modeling and adaptive model regeneration for the sports sole. The design content includes the layered parametric modeling of the sports shoe midsole based on foot shape, finite element analysis and optimization of sports shoe midsole model mechanics,

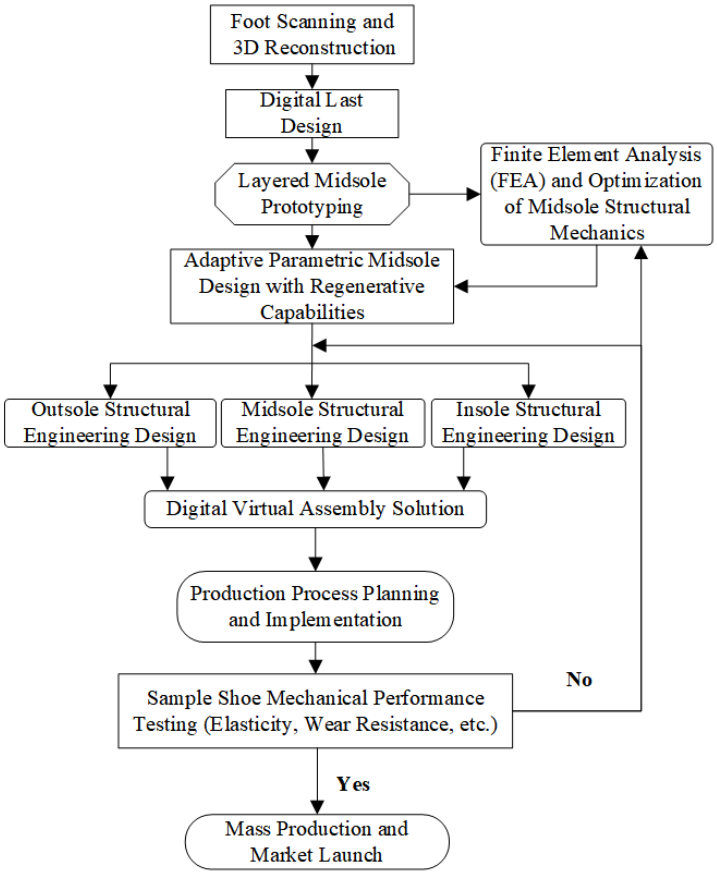

Fig. 1. Design framework of recycled sneakers based on 3D parametric modeling and adaptive model

and the virtual matching design of three parts of the sole structure. This design process of a regenerative sports sole based on three-dimensional parametric modeling and an adaptive model (as shown in Fig. 1) uses a foot scanner to obtain a three-dimensional model of the foot [14], and then reconstruct the digital shoe last according to the scanned three-dimensional model structure and data [7]. The reconstructed three-dimensional digital shoe last is the basis for the structural design of the following three parts of the sole. Secondly, according to the digital model of shoe last, the extracted two-dimensional sole contour is imported into the three-dimensional digital design platform Creo Parametric® as a sketched contour, and the layered modeling and three-dimensional parametric design of the sole structure are carried out. The mechanical finite element analysis and optimization of the midsole structure were carried out, and the optimized structure was parameterized to generate a new model. The overall digital virtual assembly design is carried out for the sole structure after the structural optimization design. If the local structure needs to be adjusted and optimized in the assembly process, it will be returned to the separate model of the sole structure for correction. If the matching of the midsole, outsole and insole of the sole structure meets the design requirements, the sample will be manufactured. After the mechanical property test of the sample sole, if the mechanical property does not meet the use requirements, the model structure design will be modified to meet the requirements. The design scheme of sports shoes will be put into actual batch production and put into the market. [7]. The reconstructed three-dimensional digital shoe last is the basis for the structural design of the following three parts of the sole. Secondly, according to the digital model of the shoe last, the extracted two-dimensional sole contour is imported into the three-dimensional digital design platform Creo Parametric® as a sketched contour, and the layered

NO.	Parameter	Left Foot	Right Foot
0	Foot length	234.014	233.978
1	Toe diagonal width	80.936	82.729
2	Anterior width of metatarsophalange	82.593	81.090
3	Metatarsophalangeal oblique width	85.244	87.084
4	Toe oblique circumference	183.916	184.593
5	Anterior circumference of metatarsophalange	190.255	185.235
6	Metatarsophalangeal oblique circumference	205.862	207.322
7	Foot waist circumference	205.001	205.943
8	Tarsal circumference	206.074	207.858
9	Back circumference	213.915	213.770
10	Foot arch height	5.058	5.061
11	Tarsal height	48.987	50.404
12	Location length	147.359	147.336
13	Thumb flip angle	10.540	9.989
14	Heel width	63.842	62.438
15	Thumb height	21.892	19.377

Table 1. Foot shape data of 3D intelligent plantar scanning instrument

Fig. 2. Stl format model of foot type 3D point cloud

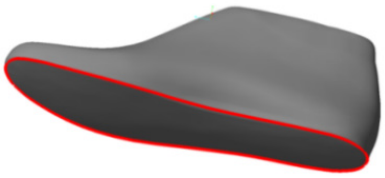

Fig. 3. Extraction of sole contour of shoe last

modeling and three-dimensional parametric design of the sole structure are carried out. Mechanical finite element analysis and optimization of the midsole structure are carried out, and the optimized structure is parameterized to generate a new model. The overall digital virtual assembly design is carried out for the sole structure after the structural optimization design. If the local structure needs to be adjusted and optimized in the assembly process, it will be returned to the separate model of the sole structure for correction. If the matching of the midsole, outsole and insole of the sole structure meets the design requirements, the sample will be manufactured. After the mechanical property test of the sample sole, if the mechanical property does not meet the use requirements, the model structure design will be modified to meet the requirements. The design scheme of sports shoes will be put into actual batch production and put onto the market.

Compared with the traditional experiential design method of sports shoes, the new method uses layered parametric modeling based on foot shape, which not only reduces the pressure of repeatedly creating complex models, but also integrates the digital virtual assembly design and finite element mechanical analysis of the sole into the design process in advance, which can predict the compatibility between the mechanical properties of the sports sole structure and the foot shape before actual manufacturing, and improve the efficiency of sports shoe research and development. This article will focus on the parametric modeling and digital virtual assembly of sports shoe soles based on foot shape. Subsequently, based on the parameterized sole model, further research will be conducted on its mechanical finite element analysis and optimization design. This part will be elaborated in detail in the next paper.

3. 3D digital shoe last reconstruction based on foot shape

3.1. Experimental instruments

In this paper, a 3D intelligent plantar scanner was used to collect foot data, model LSF-350. This was used to obtain human foot shape data and a 3D point cloud model, which provided the basis for subsequent reconstruction of the 3D digital shoe last model.

3.2. Experimental data collection and creation of digital shoe last

In this study, a 3D intelligent plantar scanning instrument was used to scan the feet of a female experimenter (female) with a common Egyptian foot shape in Fujian, China. As the parameterized sole model can quickly generate different feature types of sole models by adjusting local parameters, the method of collecting a large number of samples and calculating the mean was not used to determine the foot shape parameters. Instead, a digital shoe last model was created using the specific foot shape of a single experimenter as the collection object, which was more in line with personalized foot design.

The foot shape 3D point cloud model (shown in Fig. 2) and foot shape data (shown in Table. 1) were measured by the 3D intelligent plantar scanning instrument. The three-dimensional digital shoe last was reconstructed from the foot shape data obtained by the plantar scanning instrument and point cloud data in 3D stl format. Here, Shoemaster software was used to realize 3D digital shoe last creation. From the data in Table1, it can be seen that the experimenter's foot length is 234 mm, which belongs to Chinese shoe size 37. The 3D digital shoe last is reconstructed

and designed according to the measured size value and 3D point cloud data, as shown in Fig. 3.

4. Construction of 3D digital model of sports sole

4.1. Create 3D model of midsole in layers

The initial model of the midsole is created from the digital shoe last. There are many ways to create a 3D model of a midsole. Generally, the commonly used modeling methods are mainly to create the main body of the side wall features of the insole by extruding the surface at a certain draft angle from the midsole contour, or to build the overall skeleton contour of the space of the sole structure [15]. Different modeling methods will have a great impact on the subsequent model parameterization control. In this paper, a layered modeling method for creating a midsole was innovated. The midsole structure is divided into a multi-level cross-section control along the height direction. The cross-section shape of each layer establishes a mutual constraint relationship. The cross-section of each layer controls the size of the length direction of the midsole and that of the width direction of the midsole in the longitudinal direction; and the distance between multi-layer cross-sections in the height direction controls the height of the sole. The spatial shape of the section is controlled by extracting the overall curve shape from the toe part at the bottom of the last to the heel, so as to ensure that the foot shape conforms to the actual ergonomic design, and the upper surface of the midsole can better fit the shape of the plantar. In the three-dimensional engineering design software Creo Parametric®, the original three-dimensional model of the shoe midsole is created by boundary blending, surface merging, Boolean operation and surface modeling. We used this software to complete the 3D layered model design. Next, we will elaborate on its design process.

The process of creating the layered insole model is shown in Figure 4: ① Extract the bottom contour of the 3D digital shoe last and import it into the 3D engineering design software platform for secondary reconstruction design to create the longitudinal control surfaces of the upper surface, lower surface and middle part of the midsole. This part is designed according to the principle of ergonomics, and the structural design of the midsole should meet the performance requirements, such as the characteristics and stability of the foot structure. The upper surface of the midsole is created according to the curve contour of the sole. The overall curve is extracted from the toe of the last to the heel to create a surface, so as to improve the fit performance between the foot shape and the sole. The lower surface of the midsole is the part in contact with the ground. When creating the surface, we should focus on the balance stability of the overall force when the part is in contact with the ground and on the contour characteristics of the foot bottom. Therefore, the lower surface of the shoe maintains a horizontal surface from the heel to the forefoot, and an upward curved surface is set from the forefoot to the toe. The design of this part fully considers the application of the ergonomics principle in the design of the sole layered structure. The middle surface of the midsole model is in the middle position, which is mainly used to control the smooth transition of the structure of the sole along the height direction. Its shape is created by referring to the upper surface structure of the midsole. ② The contour of the sole extracted from the bottom of the digital shoe last is projected onto the upper surface of the midsole, and the contour curve of the upper surface of the midsole is obtained. The contour of the sole extracted from the bottom of the digital shoe last is scaled up and transformed as a whole, and then projected onto the longitudinal surface controlling the shape of the middle part of the midsole to obtain the contour curve of the middle layer. In the same way, the shape contour curve of the midsole bottom is obtained. ③ Wrinkling and distortion are easy to occur in the process of curve creating surface. ④ To ensure the generation of smooth and compliant surfaces, return to the curve construction step, add control constraint points and curves, and further fine control the curve contour. ⑤ Create an edge curve controlled along the height direction, which further accurately controls the shape of the side structure of the midsole, and updates to generate a smooth and compliant irregular surface shape. ⑥ The upper and lower longitudinal control surfaces and side surfaces of the midsole are combined, and the overall shape surface of the midsole is created through Boolean operation. ⑦ The surface structure of the created midsole shape is filled as a solid, and the layered 3D solid model of the insole is created.

The layered modeling method divides the structure of the insole model into multiple control layers, and each control layer can independently define the relevant dimensions and constraints, providing feasibility for the subsequent parametric control of the shape of the model.

4.2. Parametric model creation of sports midsole

Next, the layered 3D model midsole structure created in Fig. 4 above is parametrically designed to quickly regenerate the personalized flexible design midsole model with different needs. Parameterization defines the constraint relationship between elements, establishes the mathematical relationship between dimensions, and controls the shape and size of the model. When a certain size of the product is locally changed, the overall structure will adaptively update the model structure according to the created size, constraint and other relationships, and create a layered parameterized regeneration digital model. The system diagram of our innovative layered parametric regenerative digital model design process is shown in Fig. 5. The layered parametric regenerative digital model design mainly includes the definition design of size parameters and the design of the relationship between sizes. Next, the process is described in detail.

In the 3D design software system Creo Parametric ® ,based on the layered model created in Fig. 4, the size parameters and element constraint types between

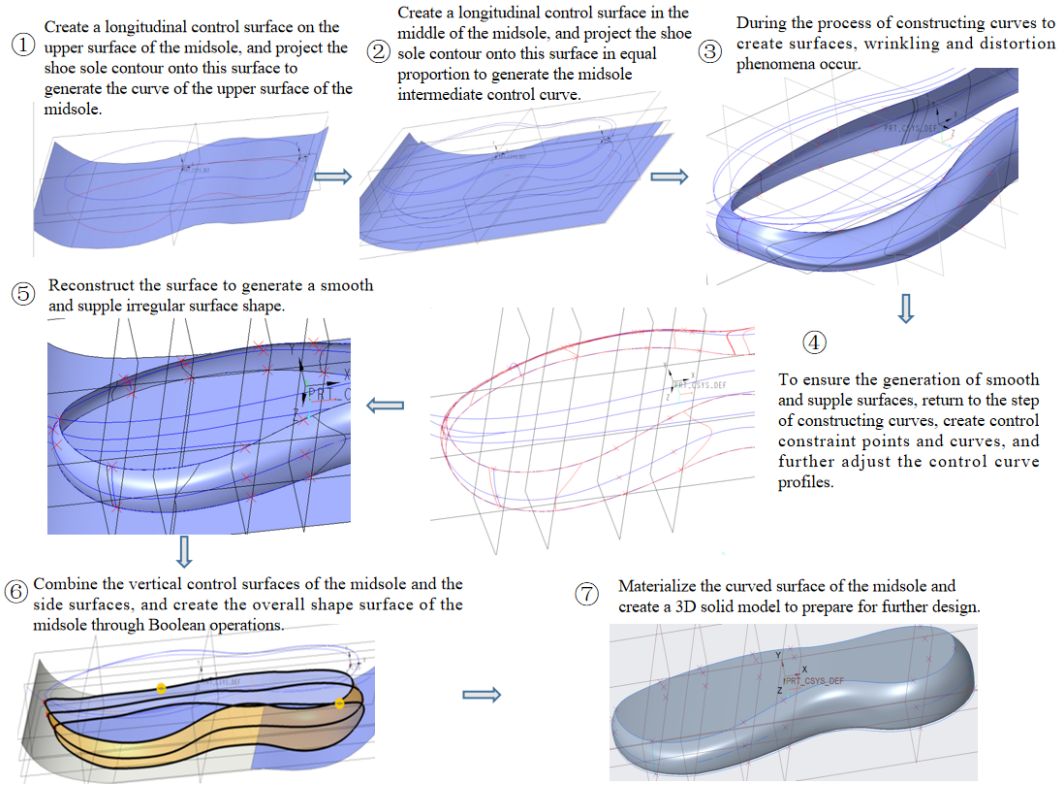

Fig. 4. Layered modeling process of the midsole in sports shoes

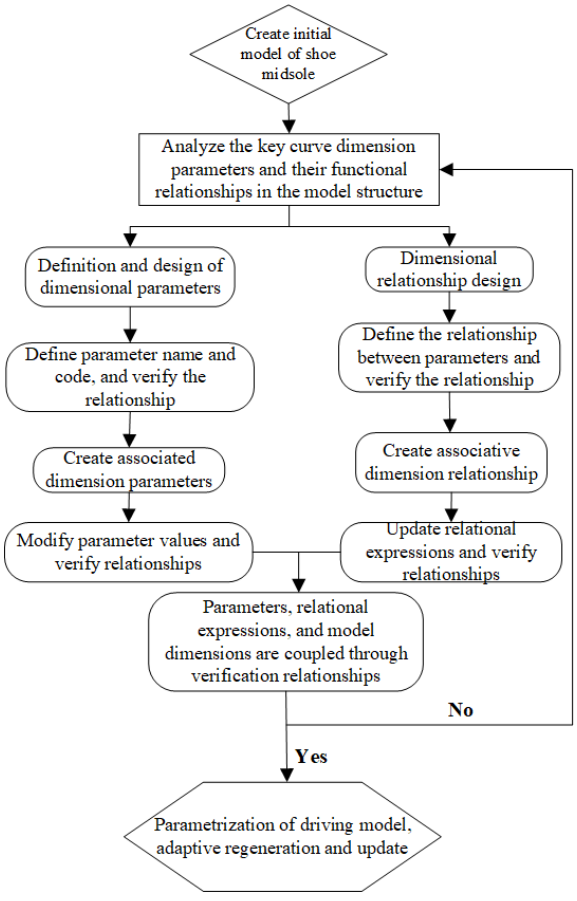

Fig. 5. Parametric design process of shoe midsole model

the contour surfaces of each layer of the model structure are analyzed. A parametric relationship between the horizontal, vertical, and height directions of the sketched outline of the sole is created. Since the sole contour is the contour curve extracted from the bottom of the last, the dimensions and constraints between the contour entities of each layer of the surface are disorderly (as shown in Fig. 6). It is necessary to reset the datum of the graphic size definition according to the shape of the entities of the model control layer, mark the fixed size, positioning size and related constraints between the entities, and standardize the dimensions and constraints of the sole contour.

In the spatial projection system, first of all, the dimensioning method of the outline structure shape of the midsole is standardized. The spatial plane projection axis passing through the length direction of the insole is used as the datum of the longitudinal dimensioning, and the spatial plane projection axis passing through the middle width direction of the midsole outline is used as the datum of

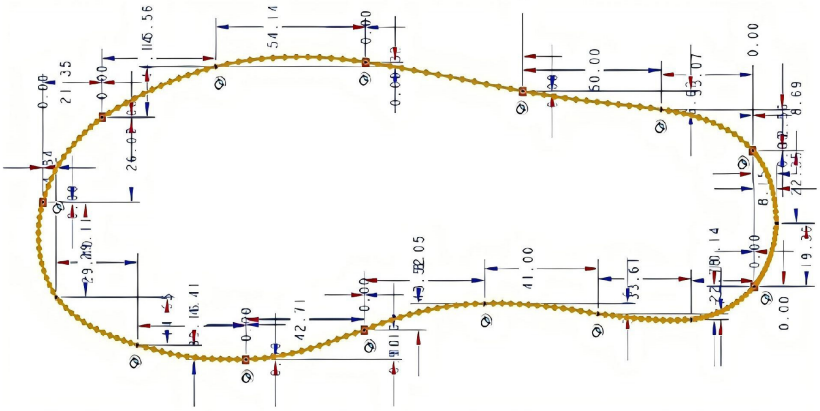

Fig. 6. Initial contour drawing of sole extracted from digital shoe last

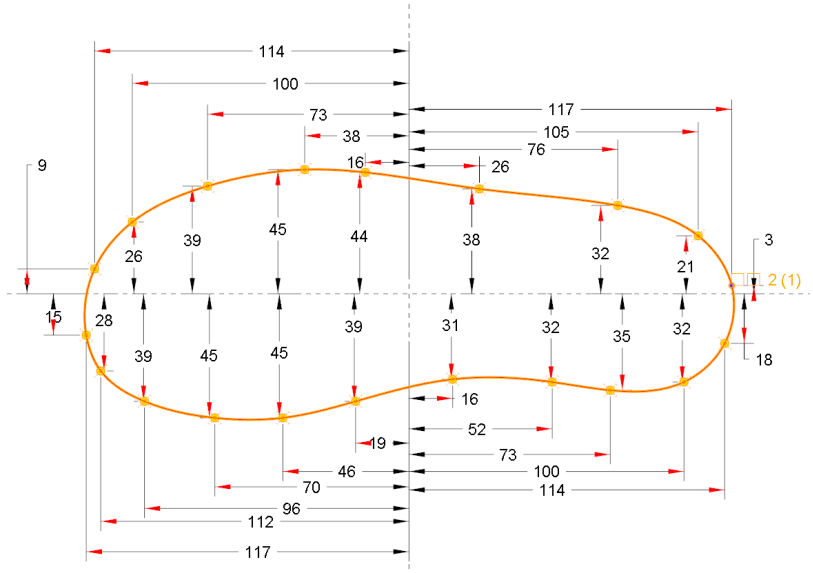

Fig. 7. Design drawing of length and width orientation and shape setting dimension marking of midsole contour

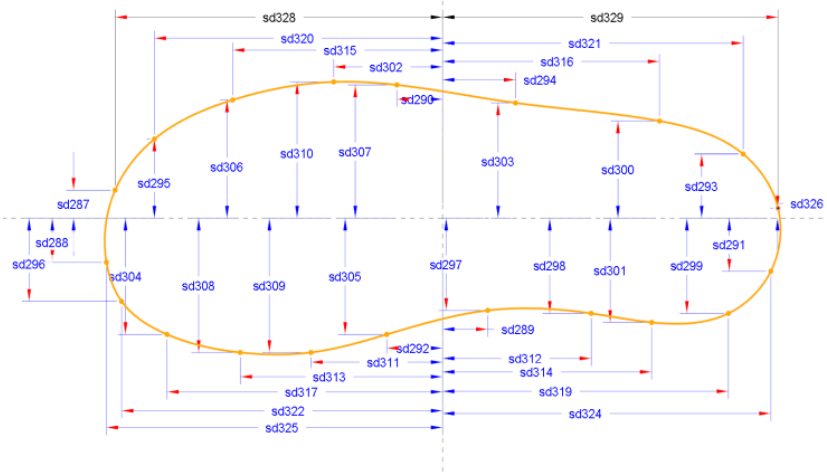

Fig. 8.Sketch of the outline of the midsole of shoes displaying the dimension code after redimensioning and constraint

the transverse dimensioning. The contour control points are used to create the transverse and longitudinal dimensions. The upper and lower dimensions control the width direction of the midsole structure, and the length direction dimensions are marked on the left and right. The shape setting and positioning dimensions of the midsole outline are standardized and neatly arranged as shown in Fig.7, in preparation for the parametric control of subsequent procedures. The size code is shown in Fig. 8.

The structure of the midsole contour is analyzed, and the size parameter at the widest part of the forefoot in the sketch of the midsole is selected as the user-defined control size. The size code system defaults to sd309. The parameter name can be self-defined according to the size attribute, and the attribute is set to user-defined. Here, we define the size name of the width direction of the insole contour as the letter W plus number, the size name of the length direction as the letter L plus number, and the size name of the height direction of the sole model as the letter H plus number. In the setting principle of the size relationship formula for the sketch of the sole outline, we divide the size of the midsole model into three parts: length direction, width direction and height direction. One control dimension in one direction is used as the parameter control quantity, respectively, and the others create the relationship formula according to the adjacent mathematical relationship of the adjacent control points on the contour to form a complete dimension chain annotation relationship, so as to ensure the normality of the adaptive model and avoid distortion according to the shape and size structure requirements of the midsole model.

In this example, there are 20 control points for the outline shape and size of the midsole, and the number of dimensions is 40 in total. The dimension of size code sd309 and parameter name W7 is selected as the control parameters in the width direction. The parameter name and relationship of the other width direction dimensions are shown in Table. 2. The change of the W7 parameter value

Size Code	Parameter Name	Size Value	Parameter relationship	Size Code	Parameter Name	Size Value	Parameter relationship
sd309	w7	45	w8=w7	sd329	L10	117	L1=L10
sd291	w1	18	w1=w2-15	sd291	L1	117	L10=L1
sd299	w2	32	w2=w3-3	sd299	L2	105	L2=L1-12
sd301	w3	35	w3=w4+2	sd301	L3	76	L3=L2-29
sd301	w4	32	w4=w5+1	sd301	L4	26	L4=L3-50
sd297	w5	31	w5=w6-8	sd297	L5	16	L5=L4-10
sd305	w6	39	w6=w7-6	sd305	L6	38	L6=L5+22
sd308	w8	45	w8=w7	sd308	L7	73	L7=L6+35
sd304	w9	39	w9=w8-6	sd304	L8	100	L8=L7+27
sd296	w10	28	w10=w9-11	sd296	L9	114	L9=L8+14
sd288	w11	15	w11=w10-13	sd288	L11	112	L11=L10-5
sd287	w12	9	w12=w11-6	sd287	L12	96	L12=L11-16
sd295	w13	26	w13=w12+17	sd295	L13	70	L13=L12-26
sd305	w14	39	w14=w13+13	sd305	L14	46	L14=L13-24
sd310	w15	45	w15=w14+6	sd310	L15	49	L15=L14+3
sd307	w16	44	w16=w15-1	sd307	L16	16	L16=L15-33
sd303	w17	38	w17=w16-6	sd303	L17	52	L17=L16+36
sd300	w18	32	w18=w17-6	sd300	L18	73	L18=L17+21
sd293	w19	21	w19=w18-9	sd293	L19	100	L19=L18+27
sd326	w20	3	w20=w19-20	sd326	L20	114	L20=L19+14

Table 2. Design of parameter name, size code and size value relationship in the width direction and length direction of the sketch outline of the shoe midsole

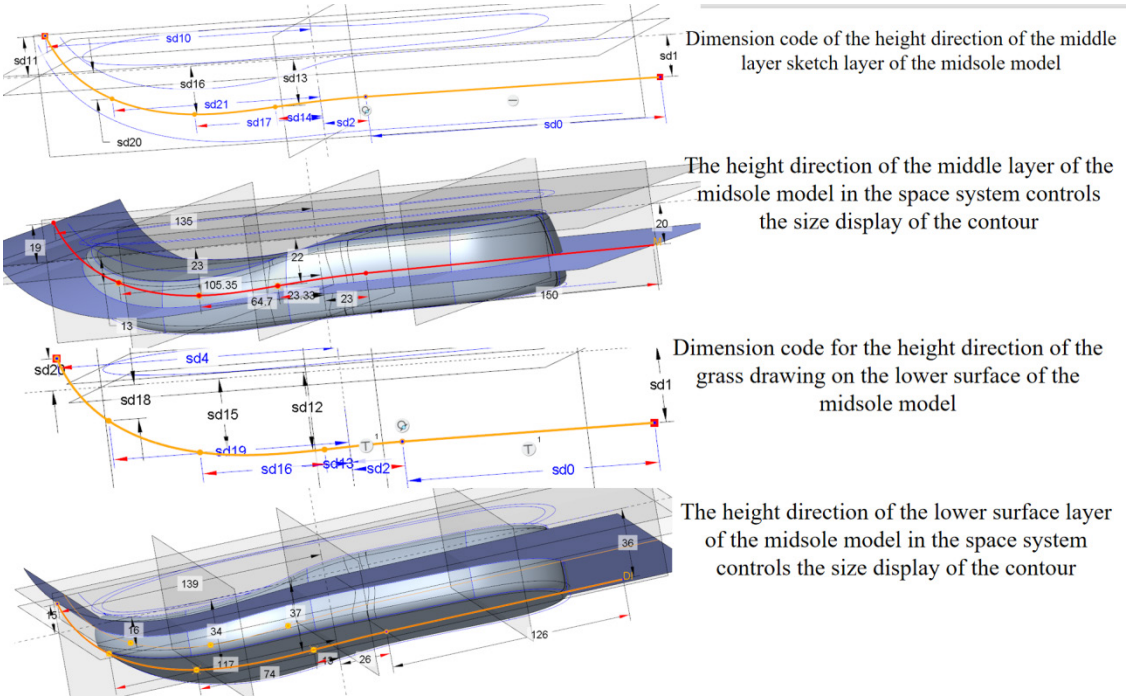

Fig. 9. Definition and design of some dimensional parameters in the thickness direction of the midsole model

will be associated with other dimensions that need to be controlled. The parametric design method for the length direction is the same. Next, we select size code sd329 and parameter name L10 as the control parameter for the length direction. The same method is used for the parametric design of the height direction of the midsole model. The size definition between the height direction layers is shown in Fig. 9. Size code sd1 and parameter name H1 are the control parameters of the height direction. The name and relationship of the size creation parameters are shown in Table. 3. The parametric design of the layered midsole model in the length direction, width direction and height direction is completed.

Next, we determine the parameter variables to be controlled according to the type of parametric model to be created, define the parameter name and code, use the program code to create the associated dimension, define the relationship between parameters, and finally create the verification relationship to complete the creation of the layered parametric renewable digital midsole

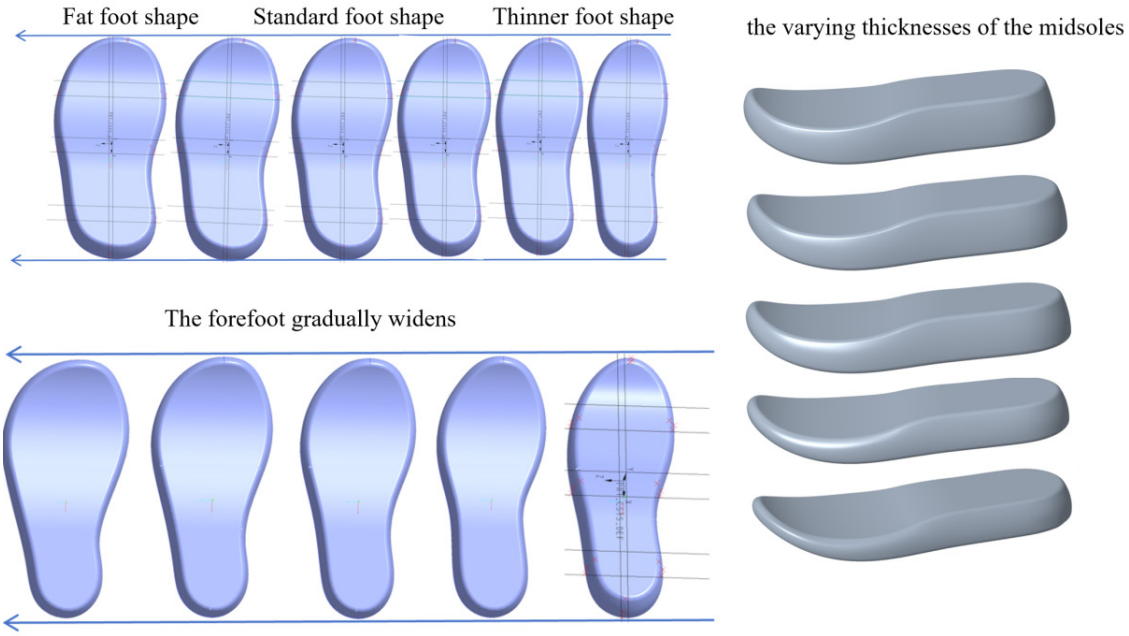

Fig. 10. Parametric generation of different types of new models

Size Code	Parameter Name	Size Value	Parameter Relationship
sd1	H1	36	36
sd12	H2	37	H2=H1+1
sd15	H3	34	H3=H2-3
sd18	H4	16	H4=H3-18
sd20	H5	15	H5=H4-1
sd1	H6	20	H6=H1-16
sd13	H7	22	H7=H6+2
sd16	H8	23	H8=L7+1
sd20	H9	13	H9=H8-10
sd21	H10	19	H10=H9+6

Table 3. Names, codes and relationships of some key parameters in the height direction of the midsole model

model. According to the diversity of foot type structure, foot types are mainly divided into Egyptian foot, Greek foot and Roman foot; From the perspective of the foot, foot types can be divided into the standard type, fat type, thin type, and wide forefoot type. When the design of the same shoe size and different foot types is realized, the relevant dimensions that need to be parameterized shall be selected. For example, the parameterization of the narrow to wide forefoot model requires controlling all dimensions of the forefoot half of the midsole contour for parametric design. The parameterized model of the fat and thin foot types needs parameterized design for the contour of the modified midsole. In this paper, taking the Egyptian foot shape as an example, the parametric models of different structural types were obtained by defining the layered parametric model to control the contour parameter value of the midsole, as shown in Fig. 10. The first row parametrically generates a gradually changing midsole structure from a thinner foot type to a fat foot type, the second row a changing structure with a wider forefoot, and the second column a series of midsole structures with different thicknesses.

For various types of foot structure to achieve parametric regeneration design of the model, the key is to explore the law of model change. For example, for the standard foot type with the same size, the fat and thin of the foot type are different, which will also lead to confusion in choosing the suitable shoe type. Shoes with appropriate length but insufficient width will pinch the feet. For the thin foot type, the shoes with appropriate length and too large width will not fit the feet, which requires personalized design for fat foot type and thin foot type people. For a foot with a wide forefoot, the shoes designed by the standard foot model are obviously not a fit. The parameterized midsole model is used to generate the corresponding structure to solve the problem of comfort of special foot types.

4.3. Structural design of insole and outsole of sports shoes

In the previous article, the structure of the sports sole is divided into three parts: outsole, midsole and insole. Fig.10 shows the completion of the layered parametric modeling of the midsole model. Next, we use the Egyptian foot shape as an example to illustrate the application of the layered parametric model in the creation of the insole and outsole structure. The midsole determines the overall stability, resilience and other stress conditions of sports shoes. The insole is the part that directly contacts with the skin of the

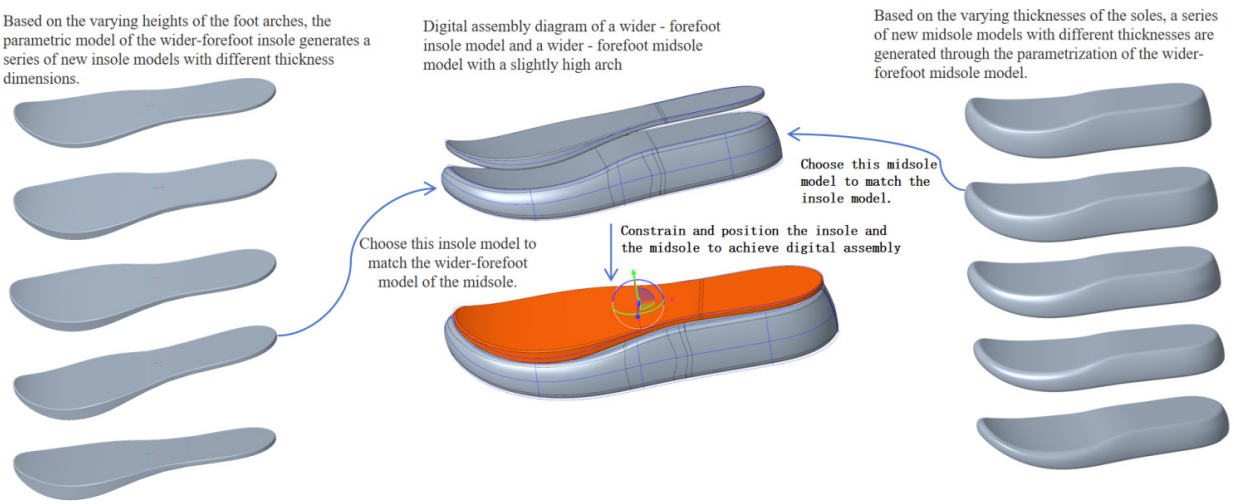

Fig. 11.Parametric design and digital assembly of insole

plantar of the human foot and is located above the structure of the midsole of the shoe. The design principle is to conform to the structure of the foot shape and maintain softness and comfort. Insoles also play an important role in the correction of special foot types, such as flat feet or high arches. In this paper, the parametric model of the Egyptian foot with a wider forefoot is selected as the benchmark, and the upper surface sole contour of the model is extracted as the contour of the insole. According to the concept of layered modeling, the insole model is completed. In order to meet the needs of a flat foot, normal arch and high arch, some parameters of the forefoot were selected for the parametric model, and a series of insole models were obtained, shown in the left part of Fig. 11. The right side of Fig.11 shows that we have generated a series of new models with different midsole thicknesses by controlling the parameter dimensions of the midsole thickness direction according to different sport's needs according to the parameterized midsole model with a wider forefoot. We select one of the insoles and midsoles to complete the matching assembly design of insoles and midsoles and then verify the matching of position, size and structure through the virtual and visual assembly relationship. If there is any error, return to the corresponding model for correction, and regenerate anew model to realize a matching interactive design between the sole structures.

The outsole structure of the sports sole is located under the midsole and is in contact with the ground to protect the midsole structure and the ground from skid. Here we still need to consider the ergonomic design principles, focusing on the wear resistance design of the outsole and the anti-skid safety design. Because the midsole has the mechanical properties of maintaining overall stability and resilience, its materials are generally TPU, EPU, EVA and other foam materials, which are light in texture but not wear-resistant. The independent outsole model can focus on the design of the patterns of the sole according to the purpose of the shoe to achieve its anti-skid, grip and other functions. We combine the bionics Tyson polygon structure and the analysis of the concentrated area of the sole pressure area [10,17] to create the anti-skid texture of the outsole. In reference [16], the Tyson polygon structure with hexagonal soles of tree frog feet is used, which has good adsorption. Based on the bionics Tyson polygon structure design method [16], combined with the situation that the force on the sole is distributed in the forefoot and heel, we made an evolution of local shape of the texture of the outsole, and created an irregular polygon structure as the anti-skid texture of the outsole, which is mainly distributed in the forefoot and heel. The outsole is generally made of rubber material with good elasticity and wear resistance, but the density of rubber material is large and heavy. Therefore, the outsole structure is designed as a sheet polygon structure of local modules, which is mainly distributed in the forefoot and heel area of the sole where the stress is concentrated. In order to reduce the direct impact of the ground on the heel during strenuous exercise, we set a hollow structure in the center of the heel of the outsole pattern. When the heel is severely impacted, this structure can make the heel center get better cushioning. Fig. 12 shows the design process of the outsole structure: the outsole shape is designed based on the midsole contour, and the texture of the forefoot and heel is drawn with the outsole contour as the boundary. It is mainly divided into three independent sheet structures, and the polygons of each part are associated with each other to maintain a closed ring of a complete sketched contour, which is convenient to realize the fourth step in Fig. 12 to stretch and extrude the thickness of the sheet texture. Here, the uniform 3mm thickness of the outsole is set to complete the modeling of the outsole structure. The fifth step is to complete the parametric model of the midsole and the digital virtual assembly of the outsole structure.

We selected one of the insoles, midsoles and outsoles for matching assembly design. Next, we verified the matching of position, size and structure through the virtual and visual assembly relationship. If there is any error, return to the corresponding model for correction and regenerate the new model. During the assembly process, there was a problem of insufficient matching accuracy between

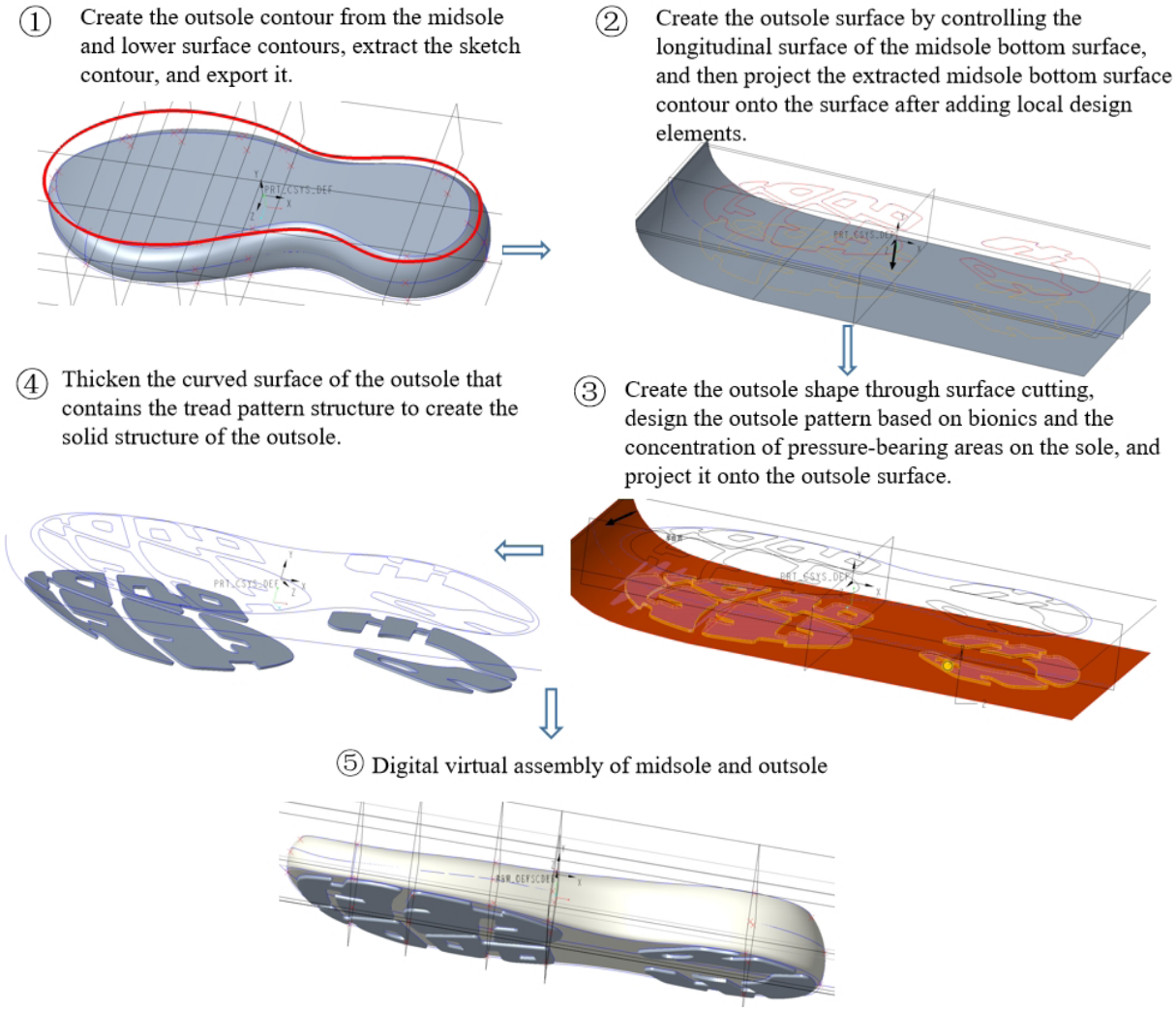

Fig. 12. Design process of outsole shape and digital virtual assembly of midsole and outsole

the sole structures shown in Fig. 13. The insole and the midsole did not fit completely, and there were gaps. In the assembly environment, when the relative position of the assembly is displayed, find out the control curve causing the structural error of this part in the insole structure, revise the structural control curve of this part of the insole to make it fit the upper surface of the midsole structure, and eliminate the error gap, so as to realize the matching interactive design.

Through the digital virtual assembly design method, the interactive matching design of the three parts of the sole structure, including the midsole, insole and outsole, based on the foot shape is realized. These three parts of the structure are independent models, but they can be matched and fused with each other. If the matching error of the size or structure of the three parts of the sole is large, the corresponding independent model is returned to modify the structure and regenerate the model. The problem of fitness between sports sole structures is solved.

5. Summary and discussion

With the rise of Internet shopping and the development of digital technology, people's choice of shoes has changed greatly, and the design to meet personalized needs has attracted more and more attention. The innovative shoe sole layered parameterized modeling method based on foot shape in this article can quickly generate shoe sole models with different structural requirements by controlling parameters, solving the problem of repeated modeling of complex shoe sole models and effectively shortening the development cycle of sports shoes. The virtual assembly interaction design of the outsole, midsole and insole of the sports sole structure realizes the prejudgment of the fitness between sports sole structures before production. Meanwhile, the layered parameterized midsole model of sports shoes provides an interactive and reproducible digital model for the mechanical analysis and optimization design of sports shoe sole structures.

Subsequently, further exploration will be conducted on the finite element analysis of layered parameterized shoe sole models in terms of mechanics,

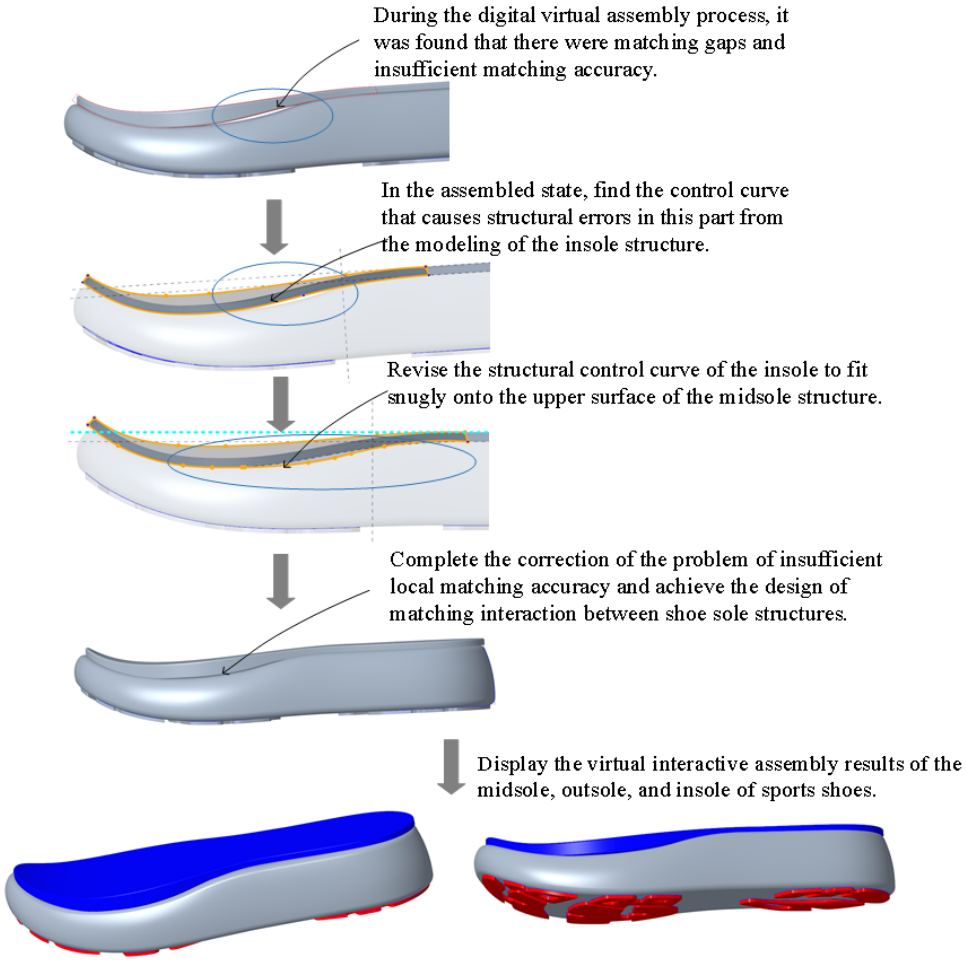

Fig. 13. Matching design between sole structures

and further research will be conducted on the optimization design of the mechanical performance of sports shoe soles. Optimization values will drive the regeneration of parameterized models, achieving the coupling design of comfort, lightweight and other structural designs of shoe sole structures with complex parameterized model regeneration. This will provide feasible references for the research and development of high-quality and personalized functional sports shoe soles.

Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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