A Review of Research on Shock Absorbing Sports Soles

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Abstract: The shock-absorbing sports sole can reduce the risk of sports injury and perform physical exercise, and can be widely used in sports fitness, auxiliary rehabilitation and other scenarios. The research progress of shock-absorbing sports soles is systematically expounded. the research on shock-absorbing sports soles at home and abroad is reviewed. Classing accord to shock-absorbing materials, shock-absorbing structures, shock-absorbing performance evaluation. Summarizing emphatically the characteristics of shock-absorbing materials performance and innovative applications, shock absorption principle of shock absorbing structure, analysis of advantages and disadvantages of shock absorbing structure, methods of shock absorption performance evaluation. Analyzing and prospecting the key technologies and future development trends of sole shock absorption material, shock absorption structure, shock absorption performance evaluation.

1 INTRODUCTION

With the development of society, our country has entered the stage of population aging. With the growth of age, the physiological functions of the elderly gradually decline. Various chronic diseases of the elderly increase. Their needs for health are more urgent. According to the relevant experimental research of the American Exercise Association, appropriate and reasonable physical exercise can improve the physical health of the elderly to a certain extent (Zixin X, 2018). As an essential equipment for fitness exercise, sports shoes must have the following characteristics: lightweight, air permeability, elasticity, shock absorption and stability, anti-skid, wear resistance and bending flexibility, among which the shock absorption performance of sports shoes can enhance the impact resistance of sports shoes and avoid damage to the body caused by impact (Benmin Z, 2020).

In 2012, Yuancai Zhang applied novel plantar pressure test system and shock absorption impact test instrument to test the plantar pressure and shock absorption performance of 5 pairs of sports shoes with arch structure design. The results showed that the shock absorption of the sole was related to the sole material and sole structure design. When the sole material was softer, the stress of the sole structure was balanced, the smaller the pressure on the human foot, the better the shock absorption effect. In 2016, Yi Zheng et al. in order to analyze the impact of sole hardness on shoe cushioning performance and sports injuries, tested sports shoes with different sole hardness through running experiments, and collected the kinematic indicators of human lower limbs. The results showed that 30° and 40° sole hardness had a good cushioning effect, which could reduce the risk of sports injuries on the feet. In 2019, Sicheng Ke et al. conducted 20 / 40 / 60cm landing tests on 12 subjects that wore three different shock-absorbing soles, in order to study the shock-absorbing performance of the soles. The experimental data showed that the softness of the soles affected the peak pressure of the soles, smaller the peak pressure of the soles, better the shock-absorbing effect. In 2021, Hongying Jiang arranged 10 subjects to conduct landing experiments in order to study the impact of different sports sole hardness on the biomechanics of lower limbs. The results showed that a softer sole would reduce the impact of ground reaction force on lower limbs.

The above research shows that the shock absorption performance of sports shoes is related to sole materials and sole structure. Therefore, this paper mainly expounds sole shock absorption materials,

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sole shock absorption structure, shock absorption performance evaluation and sole forming technology.

2 SHOCK ABSORPTION OF MATERIAL

The so-called shock absorption performance refers to the ability of the sole to absorb and reduce the vibration wave caused by movement (Pei Y, 2017). The most important factor that directly affects the shock absorption performance of sports sole is sole material and structure. Material shock absorption refers to the use of special materials with shock absorption performance in the midsole of sports shoes (Li L, 2015). The material deformation occurs after impact to prolong the impact time. The midsole refers to the part between the outsole with anti-skid effect and the shoe body, which is an important component to ensure that sports shoes have good cushioning, shock absorption and energy return. The midsole directly affects the function and comfort of sports shoes.

EVA (thermoplastic resin material) and TPU (thermoplastic elastomer) materials are widely used in the midsole of sports shoes, which are light weight and strong comfort, good shock absorption effect. TPU shoe materials account for about 40% of the domestic TPU market share (Tingting N, 2021; Wenhui Y, 2015). As a high-performance material, GEL and P4U material can be applied to high strength protection market, which has excellent performance such as shock absorption, energy absorption and cushioning (Heaven Has Feathers, 2021). So this paper describes four kinds of shock absorption materials, EVA, TPU, GEL, P4U.

2.1 EVA Shock Absorption Material

EVA material is a thermoplastic resin material, which is widely used in the field of shoe materials and the most commonly used material for shoe midsole. In 2001, Mills et al. studied the shock absorption of EVA material and found that the smaller the volume of the internal void of EVA material, the worse the shock absorption effect. In 2004, Verdejo et al. discovered that long-term exercise could cause structural damage to the EVA foam on the sole, thus losing the cushioning effect. The disadvantage of this material is that the internal structure of the material is easy to be damaged by extrusion and lose the effect of shock absorption.

In 2018, Jiyu Liang et al. analyzed the properties and structures of EVA and BIIR / EVA foamed materials, the study found that the increase of EVA composition of BIIR / EVA foamed materials would improve the hardness and mechanical strength of foamed materials.

2.2 TPU Shock Absorption Material

TPU thermoplastic polyurethane, a kind of linear block copolymer composed of soft and hard segments, is one of the most widely used engineering thermoplastic elastomers at present (Tongyu Z, 2020). In 2016, Yanna Zhang et al. investigated the properties of new TPU foamed material, found that the TPU foamed material was light and elastic. In 2020, Zhiyuan Xin et al. carried out modification experiments on TPU materials, the results showed that the modified TPU materials had better softness and elasticity, the compression set of TPU / OBC infuse modified materials was the smallest. Compared with EVA material, TPU foamed material has lower modulus, higher energy efficiency and lower compressive brittle deformation, which is applied in the field of sports' shoes (Wei W, 2019).

The material can be applied not only in footwear products, but also in cushioning packaging structure. In 2019, Xiaoyi Chen printed TPU (semi soft 3D material) into buffer pad with one or two layers of hollow structure, the experimental data showed that the buffer pad of TPU material after 3D printing had good cushioning performance.

2.3 Shock Absorbing Gel Material

In 1986, Asics introduced a shock-absorbing gel, which is a soft rubber material between solid and liquid. Comparing with the same volume of EVA foam, GEL material reduces the weight by half, and increases 10% elasticity and 20% shock absorption. GEL material provides elastic and energy feedback for all kinds of sneakers. Asics's gel-kayano shock-absorbing shoes series will distribute the GEL in front and back of the sole in order to provide better buffering effect (Zhi Q, 2013). In addition to GEL, there is also an intelligent P4U material, which has been used in sports. In 2019, the Peak team released its own adaptive midsole technology-P4U, a gel material based on mechanical state transition principle. P4U material dynamic mechanical properties can achieve transient state transition and make adaptive adjustment. P4U material is in a fluid state at low speed of human body sports, and in a solid state at high speed of human body sports. P4U material has impact resistance, protection, shock absorption and other properties. This cushioning gel material is not only used in sports field, but also used in electronic equipment, automotive protection, modification materials, military and other aspects (Clifton P, 2011).

Although the shock-absorbing material is high protection performance and shock-absorbing performance, which can be placed in the midsole to absorb impact force. But the material itself is in a soft gel state and can not be combined with the shock absorbing structure of the sole to play a dual role in reducing vibration.

3 SHOCK ABSORPTION OF STRUCTURE

Previous studies on running shoes focused on the occurrence and prevention of plantar injury. In 2014, Yaodong Gu et al. found that the unstable sole structure could adjust and control the movement of lower limbs through the sole experiment, and then verified that the unstable sole structure could adjust the walking posture and guide the rehabilitation training. In 2015, Agnes Huebner et al. conducted the experiment on safety shoes with cushioning heel insert, found that adjustable heel insert could reduce muscle activity and strain fatigue. In 2017, Weijie Fu et al. learned through human landing experiment that the shock absorption of shoes played a limited role in mitigating impact force, but it could reduce the peak impact force during accidental landing and avoid impact damage. In 2020, Alfred Gatt et al. studied the effect of the best rigid cushioning shoes on the clinical treatment of diabetic foot, the results showed that the best rigid cushioning shoes could reduce the plantar peak pressure of diabetics.

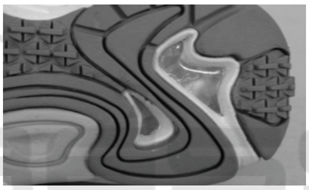
Sports shoes with shock absorption function can absorb the impact and reduce sports injury, protect the human body, so the development of sole shock absorption structure has great significance to people in sports. The existing shock absorbing structure include filling structure, bionic structure, and electromechanical structure.

3.1 Filled Structure

The working principle of airbag shock absorption is that the midsole is subjected to huge impact force, and the gas volume in air cushion will be compressed to complete the process of force relief (Dengxin W, 2013). The air cushion structure includes half palm air cushion (Fig. 1 (a)) and full palm air cushion (Fig. 1 (b)), the half palm air cushion is mainly placed in the heel, while the full palm air cushion is placed in the whole sole. Air-cushioned shoes has obvious shock absorption effect, but it can not provide thrust to assist athletes in sports (Hui S, 2005).

(a) Half palm air cushion

(b) Full palm air cushion



(c) Liquid damping pad

Figure 1: Filled sole structure.

Liquid pad is a cavity structure composed of one or more chambers, which is filled the whole chamber with liquid, similar to air cushion structure. The liquid pad can transmit the huge impact force through the liquid to the outer wall of shock absorber. The result is shock absorber deformation and converting the impact force into upward feedback force. The fluid shock absorption device (Fig. 1 (c)) used Hydroflow technology is designed based on the working principle of liquid pad (Piaolin P, 2014). The stability of liquid shock absorber pad is good, but the outer wall of liquid shock absorber pad is squeezed for a long time, which will cause compressed permanent deformation and even leak liquid.

3.2 Bionic Structure

The arch structure is deformed under compression to realize effective cushioning and rebound, reduce the impact force transmit to foot (Yong T, 2008). This half-horseshoe arch structure (Fig. 2 (a)) is composed of elastic bow piece, tension spring, balance base

(Zhao Z, 2006). The elastic bow piece reduces the impact force from the ground through appropriate deformation to avoid injury to the body. The tension spring provides the extension force for the elastic bow. The balance base is responsible for the stability of the elastic bow and tension spring in operation.

(a) Arched structure

(b) Wave structure

(c) Corrugated paper structure

(d) Grid structure

(e) Blade structure

Figure 2: Bionic sole structure.

The wave structure (Fig. 2 (b)) utilizes the mechanics of bow to disperse the impact force (Lan Y, 2016). The wave structure is not only applied in the field of footwear, but also in the field of transportation / packaging, such as corrugated paper structure (Fig. 2 (c)). A bionic structure similar to the ocean wave, which disperse the impact force through pressure deformation and protect the good from damage.

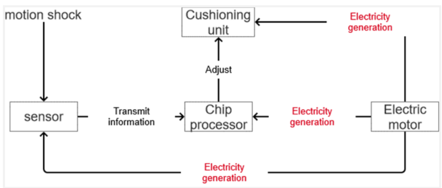
Grid structure (Fig. 2 (d)) uses the elastic of the racket line to absorb the impact force and slow down the vibration caused by the impact force (Katherine K,2008). This mesh structure with high elasticity rubber cords is applied directly under the heel.

The blade structure imitates the movement posture of athlete that is the center of the human body tilts forward and forms an angle of less than 90 degrees with the ground, provides movement potential energy and thrust. This midsole structure (Figure 2 (e)) is designed with 16 independent blades to absorb impact force and convert it into thrust to provide energy for users (Haitao W, 2017). Compares with other shock-absorbing running shoes, this running shoe has low stability and high elasticity.

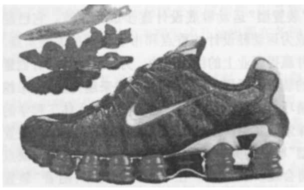
3.3 Electromechanical Structure

The sensing sole structure (Fig. 3 (a)) senses the vibration of sole movement through sensors and transmits the vibration to the chip processor (Dengxin W, 2013). The built-in chip processor is connected with the electric motor and shock absorbing unit with cables. The hardness of the shock absorbing unit can be changed by adjusting the cables through the chip processor to improve the shock absorbing efficiency (Fig. 3 (b)). Although this structure can freely change the performance of the shock absorbing unit, its deficiency is that the sensing components and built-in chip can not withstand repeated motion impact, which will cause component damage and loss of sensitivity of the sensor.

(a) Sensing sole



(b) Schematic of shock absorption



(c) Spring shock absorption

Figure 3: Electromechanical sensing structure.

Mechanical structure shock absorption is to absorb the force through the physical structure of the shock absorption system. When the structural unit is compressed to produce deformation, the force will be transformed into elastic potential energy and stored. When you take the next step, the structure will rebound and release the elastic potential energy to produce the force in the same motion direction to realize the force feedback. In 1984, Nike introduced the spring shock absorption structure (Fig. 3 (c)), which was placed in the middle of the sports sole, the shock absorption and elasticity of sports shoes are enhanced (Yong T, 2008).

4 SHOCK ABSORPTION PERFORMANCE EVALUATION

There are two ways to evaluate the shock absorption performance of sole: finite element simulation evaluation and sole impact test. Finite element simulation evaluation is to predict the shock absorption effect of the unformed sports shoe sole structure and material, optimizing the sole structure and material in advance according to the prediction result. Sole impact test is to evaluate the shock absorption effect of formed sports sole.

4.1 Finite Element Simulation Evaluation

Finite element method refers to the finite element method, which is a research method of Engineering Mechanics similar to solving continuous domain problems. The solution process is shown in Figure 4, the stress and strain of the output element are solved by introducing load and boundary conditions into the discrete element matrix, and the internal mechanical characteristics are analyzed (Tao L, 2002).

Figure 4: Finite element solution diagram.

In 2007, TM Cheung et al. established a finite element model to evaluate the biomechanical effect of heel support on foot ankle joint in order to alleviate the symptoms of plantar fasciitis, the results showed that heel support could reduce the symptoms and pain of plantar fasciitis. In 2012, Wenquan Xu et al. used the impact simulation software ANSYS / LS-DYNA to evaluate the shock absorption of sports shoes in order to provide relevant data of shock absorption performance for the structural design of sports shoes sole. It was simulated that drill bit impacted the heel of sports shoes in the software, the maximum impact force and maximum deformation of forefoot and heel of sports shoes were 790 N, 6.36 mm and 850 N, 6.18 mm. In 2020, Sicheng Ke et al. established a foot-shoe-ground finite element simulation model to simulate the stress process of sports shoes when they landed from 20cm, 40cm and 60cm heights in order to analyze the pressure distribution of soles and foots when they landed on the ground. By using three-dimensional force measuring platform and plantar pressure test system, evaluated the shock absorption performance of the sole and the verified effectiveness of the simulation model. The experimental results showed that the foot-shoe-ground finite element simulation model was effective and could evaluate the shock absorption performance of the sole.

4.2 Sole Impact Test

The sole impact test is also called material test that mainly adopts the impact testing machine, seting the metal impact head to impact tested shoes at a fixed height, and measuring the impact force on the impact head to analyze the ability of shoes or insoles to reduce the impact load.

In 2012, Jun Gao mainly elaborated the test conditions and test process of the drop hammer impact method. The test conditions included test equipment (45mm impact hammer) and samples (5mm ~ 35mm soles), impact energy (5J and 7J). The test process was that the 8.5kg impact hammer freely fallen to the surface of the insole at a specified height, simulating the stress of the sole that the human body fallen from a high place. It recorded and analyzed the maximum impact force, maximum compression displacement, and the ratio of maximum acceleration to gravity acceleration. In 2014, Jianfeng Chen researched a method to test the dynamic compressive deformation of rubber shoes soles that was tested by repeatedly impacting the soles with an impact hammer. when the more the number of impacts, the dynamic compression set rate of rubber shoes not changed much and tended to be stable. In 2016, Yunqi Tang et al. tested four sports shoes by using two methods of sole pressure test and sole impact test in order to find the evaluation index of shock absorption performance of sports shoes, the results showed that the pressure index of foot pressure test and the energy absorption index of impact test were available indexes.

5 KEY TECHNOLOGY ANALYSIS

(1) Materials and comfort. Because the shock absorption function of sports shoes is reflected in the sole material, and the heavier the shoe material, the greater the energy consumption of human movement. In addition, long-term exercise will cause sole wear. Therefore, certain requirements are put forward for the strength, quality and elasticity of shock-absorbing shoe materials. Shock absorbing shoe materials need to have the characteristics of high strength, lightweight and high elasticity. Shoe materials (EVA material and foamed TPU) are selected according to the design requirements and material characteristics to meet the daily needs of people for exercise.

(2) Structure and comfort. In terms of shock-absorbing structure, the existing shock-absorbing sports shoes focus on reducing the pressure of the sole, but this kind of design rarely considers the service cycle and stability of the structure. Therefore, study the pressure distribution area of the sole combine with anatomy and human sports mechanics to optimize the existing shock-absorbing structure. It ensures that the sports shoes absorb and disperse the sports impact beyond the bearing range of the human body, reducing the local structural damage caused by pressure concentration, improving the service cycle and stability of the sole.

(3) Evaluation of shock absorption performance. The evaluation of sole shock absorption performance is divided into virtual evaluation before sole forming (finite element simulation) and actual evaluation after shoe forming (sole impact test). Both evaluate the sole shock absorption performance through the evaluation indexes such as sole pressure, maximum impact force and deformation of sole. The accuracy of its evaluation affects the production and use of sole, so the combination of finite element simulation evaluation and sole impact test will greatly improve the accuracy of shock absorption performance evaluation. When the data comparison difference between finite element simulation evaluation and sole impact test is smaller, it proves that the shock absorption performance evaluation result of sole is more accurate, and vice versa.

6 CONCLUSION

As the base of the elderly population increases, and the demand for health industry will also increase. The elderly sports health service industry will be the focus of future development. With the increasing demand of the elderly for auxiliary rehabilitation and physical exercise, the design of shock-absorbing sneakers will have a very broad prospect.

By analyzing and summarizing the development of sole materials of shock-absorbing sports shoes, the working principle of shock-absorbing structure, the evaluation method of shock-absorbing performance, readers have a deeper understanding of shock-absorbing sports shoes. In addition, future researchers should strengthen the research on the gait and foot pressure of human lower limbs, summarize the gait law and foot pressure distribution of human body, innovate the shoe material and structure of shock-absorbing sports shoes on this basis.

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