THE SHOCK ABSORPTION FUNCTIONALITY OF NANOMATERIALS BASED SHOES DURING BODY MOTION

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ABSTRACT. The violent movement of human body will bring great impact to feet; therefore the shock absorption function of sports shoes is very important. The main factors affecting the shock absorption function is the material and structure of sole. In order to investigate the effect of nanomaterials on the shock absorption function of sports shoes, the impact tests were carried out on the thermoplastic elastomer (TPE) soles which were added or not added with nano-carbon black and the ordinary rubber soles. The impact energy was set as 6 J and 10 J, and the shock absorption performance was determined according to the test results. Thirty volunteers attended comfort tests which were designed to test the comfortability of the three kinds of sports shoes. The results demonstrated that the sport shoes which were added with the nano-carbon black had the best shock absorption performance. The impact peak value and G value of the sports shoes which were added with nano-carbon black were 13.57% and 17.86% lower than the shoes with the ordinary rubber soles when the impact energy was 6 J; the impact peak value and G value of the shoes with the ordinary TPE soles were 1.54% and 10.71% lower. When the impact energy was 10 J, the peak value and G value of the shoes which were added with nano-carbon black were 8.96% and 13.51% lower, while the impact peak value and G value of the shoes which were equipped with the ordinary TPE soles were 4.32% and 8.11% lower. The findings suggested that nanomaterials was effective in enhancing the shock absorption performance of sports shoes and that the shock absorption performance of sports shoes which were produced using nanomaterials was better than that of ordinary sports shoes. Moreover the results demonstrated that the shock absorption effect of sports shoes was limited, excessively large impact might weaken shock absorption effect.

KEY WORDS: nanomaterial, human motion, shock absorption, cavity structure, ventilation technology, comfortability

FUNCȚIONALITATEA DE ABSORBȚIE A ȘOCURILOR A ÎNCĂLȚĂMINTEI DIN NANOMATERIALE ÎN TIMPUL MIȘCĂRII

REZUMAT. Mișcarea violentă a corpului uman are un impact puternic asupra picioarelor; prin urmare, funcția de absorbție a șocurilor a încălțămintei sportive este foarte importantă. Principalii factori care afectează funcția de absorbție a șocurilor sunt materialul și structura tălpii. Pentru a investiga efectul nanomaterialelor asupra funcției de absorbție a șocurilor la încălțămintea sportivă, s-au efectuat teste de impact cu tălpi din elastomer termoplastic (TPE) la care s-a adăugat sau nu negru de fum nano și cu tălpi de cauciuc obișnuite. Energia de impact a fost stabilită la 6 J și 10 J, iar performanța de absorbție a șocului a fost determinată în funcție de rezultatele testelor. Treizeci de voluntari au participat la testele de confort care au fost concepute pentru a testa confortul celor trei tipuri de pantofi sport. Rezultatele au demonstrat că pantofii sport cu talpă la care s-a adăugat negru de fum au avut cea mai bună performanță de absorbție a șocurilor. Valoarea maximă a impactului și valoarea G a încălțămintei sportive cu talpă la care s-a adăugat negru de fum au fost cu 13,57% și 17,86% mai mici decât în cazul încălțămintei cu tălpi obișnuite din cauciuc atunci când energia de impact a fost de 6 J; valoarea maximă a impactului și valoarea G a încălțămintei cu tălpi obișnuite TPE au fost de 1,54% și 10,71% mai mici. Când energia de impact a fost de 10 J, valoarea maximă și valoarea G a încălțămintei cu talpă la care s-a adăugat negru de fum au fost cu 8,96% și 13,51% mai mici, în timp ce valoarea maximă a impactului și valoarea G a încălțămintei cu tălpi obișnuite din TPE au fost cu 4,32% și 8,11% mai mici. Constatările au sugerat că nanomaterialele au avut eficiență în creșterea performanțelor de absorbție a șocurilor și că performanța de absorbție a șocurilor a pantofilor sport fabricați folosind nanomateriale a fost mai bună decât cea a pantofilor sport obișnuiți. Mai mult, rezultatele au demonstrat că efectul de absorbție a șocurilor al pantofilor sport a fost limitat, iar impactul excesiv de mare ar putea slăbi efectul de absorbție a șocurilor.

CUVINTE CHEIE: nanomaterial, mișcare umană, absorbția șocului, structura cavității, tehnologie de ventilație, confort

LA FONCTIONNALITÉ D'ABSORPTION DE CHOCS DES CHAUSSURES À BASE DE NANOMATÉRIAUX AU COURS DU MOUVEMENT DU CORPS

RÉSUMÉ. Le mouvement violent du corps humain a un impact important sur les pieds ; par conséquent, la fonction d'absorption des chocs des chaussures de sport est très importante. Les principaux facteurs affectant la fonction d'absorption des chocs sont le matériau et la structure de la semelle. Afin d'étudier l'effet des nanomatériaux sur la fonction d'absorption des chocs des chaussures de sport, les essais d'impact ont été effectués sur les semelles en élastomère thermoplastique (TPE) ajoutées ou non avec du noir de carbone nano et des semelles en caoutchouc ordinaires. L'énergie d'impact a été fixée à 6 J et 10 J et la performance d'absorption des chocs a été déterminée en fonction des résultats du test. Trente volontaires ont participé à des tests de confort conçus pour tester le confort des trois types de chaussures de sport. Les résultats ont montré que les chaussures de sport aux semelles qui ont été ajoutées avec le nano-carbone noir ont eu la meilleure performance d'absorption des chocs. La valeur maximale de l'impact et la valeur G des chaussures de sport aux semelles ajoutées avec du nano-carbone noir étaient 13,57% et 17,86% inférieures à celles des semelles en caoutchouc ordinaires lorsque l'énergie d'impact était de 6 J ; la valeur maximale de l'impact et la valeur G des chaussures aux semelles TPE ordinaires étaient 1,54% et 10,71% inférieures. Lorsque l'énergie d'impact était de 10 J ; la valeur maximale et la valeur de G des chaussures aux semelles ajoutées avec du nano-carbone noir étaient 8,96% et 13,51% inférieures, tandis que la valeur maximale d'impact et la valeur G des chaussures aux semelles ordinaires en TPE étaient 4,32% et 8,11% inférieures. Les résultats ont montré que les nanomatériaux étaient efficaces pour améliorer les performances d'absorption des chocs des chaussures de sport et que la performance d'absorption des chocs des chaussures de sport fabriquées à l'aide de nanomatériaux était meilleure que celle des chaussures de sport ordinaires. En outre, les résultats ont montré que l'effet d'absorption des chocs des chaussures de sport était limité, un impact excessivement grand pouvant affaiblir l'effet d'absorption des chocs.

MOTS CLÉS : nanomatériau, mouvement humain, absorption des chocs, structure de la cavité, technologie de ventilation, confort

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INTRODUCTION

The foot of human body is a natural shock absorption structure. The arch of the foot plays a key role in the shock absorption of feet. During motion, feet will suffer impact when touching the ground, and may have different injuries in different parts, such as ankle sprain and tendon injury. Feet will bear multiple impacts when walking, let alone strenuous exercise [1]. According to the relevant statistics [2], the impact of feet during long-distance running was about three times that of jogging. Such a frequent and huge impact is difficult to offset by the structure of the foot itself, which will make the feet exhausted. The protection of sports shoes for feet reflects on its shock absorption property. The shock absorption of shoe sole materials has a direct impact on the shock absorption of sports shoes. In recent years, nanocomposites have been widely used in shoemaking.

Nanotechnology combines modern science and technology and has gradually developed in recent years. Nanomaterial features are low weight, strong hardness and long service life [3]. With the maturity of technology, nanotechnology can be used in daily life such as manufacture of running shoes besides aerospace, microelectronics & computer, and environment and energy. Some experts have made relevant studies. Song *et al*. [4] proposed that nanotechnology had deep influence on sports engineering field and has been extensively applied in sportswear and equipment. Considering the popularization and risks of running, Bassiri *et al*. [5] applied nanotechnology in the manufacture of shoe sole to prevent different injuries. Lutpi *et al*. [6] proposed that the application of nanocomposite in the sole of running shoes had been a new development direction. Ramsay *et al*. [7] considered that the application of nanotechnology could enhance the exercise capacity and technical level of athletes. Therefore nanomaterial has been extensively recognized and applied in shoemaking. In this study, the sports shoes whose soles were made of three different materials were tested using a shock absorption testing machine, and the vibration reduction performance of the materials was determined based on the testing results.

Nanomaterials and their Application in Shoemaking

Nanomaterial is a kind of particulate solid material whose diameter is less than 100 nm. It contains a variety of solid components, which can be crushed such as metals, nonmetals, simple substances and compounds [8]. Nanomaterials are often not directly used as raw materials for industrial production, but are used for modifying the target materials as a kind of filler material similar to “additives” to enhance the mechanical properties and save cost. Nanomaterial particles are unable to be observed by optical microscopy, but they are also not microscopic. Therefore, nanomaterials are also called mesoscopic materials; but nanomaterials have the performance which the same materials do not have in macroscopic state such as small-size effect, interfacial effect and macroscopic quantum tunneling effect [9]. The non-nanomaterials which are added with nanomaterials are called nanocomposites. Nanocomposites have been extensively applied in different fields, such as the building industry and textile industry.

Nanomaterial has an extensive application in shoemaking. Carbon black and white carbon black have been extensively applied for decades. Its compensation function can strengthen the colloid part of shoes, for example, the mechanical performance of shoe sole and heel. Nano-zinc oxide has more functions. It can have the effect achieved by ordinary zinc oxide, at a lower dosage, which can save cost and zinc resource. Therefore it can replace traditional zinc oxide in shoe colloid. Moreover the three nanomaterials shown in Table 1 all have bactericidal effect. Hence shoes which are made of one of the three nanomaterials and fibre materials also have bactericidal effect.

Table 1: Some common nanomaterials used in shoemaking

Name	Application in shoemkaing industry	Technical status
Carbon black	Mostly used in the black rubber of rubber shoes and the black heel of leather shoes and sports shoes.	The technology has been matured and extensively applied.
White carbon black	Has the same application range with carbon black, but in white or color shoes.	The technology has been matured and extensively applied.
Nano-zinc oxide	It can be used in the manufacturing of shoe heel at a dose which is half that of traditional zinc oxide, which can save cost.	Mass use in some shoe factories
	Replacing ordinary zinc oxide with less amount in the manufacturing of shoe glue	Needs to be promoted
	Being added to fibre materials, and can resist bacteria	Needs to be promoted

Shock Absorption Function of Sports Shoes

When sportsmen do exercise especially fast running, the legs will receive an impact force generated by the ground and will be injured if motion posture fails [10]. At that moment the shock absorption function of sports shoes will take effect. Sports shoes protects sportsmen by generating resistance to impact force via the changes of internal structure of shock-absorbing materials or the deformation of the special structure of sole. In simple words, function of shock absorption is the ability of absorbing or weakening shock wave.

The shock absorbability of sports shoes will be affected by the surface environment of sport field, motion posture, exercise intensity, and the hardness, thickness, materials and structure of the sole of sports shoes [11]. After excluding the human factors, i.e. motion posture and exercise intensity, the materials and structure of sports shoes is the factor which has the largest influence on shock absorbability and is controllable. A qualified sportsman will select shoes which are made of different materials and structures according to different situations. Indexes for evaluating the shock absorbability of sports shoes include impulse; plantar pressure associated indexes including distribution of plantar pressure, average pressure and changes of buffer pressure value during landing and ground reaction force associated indexes including impact force peak value, G value and maximum load rate [12].

The Shock Absorbing Materials of Sports Shoes

Material of sole is an important controlling factor which affects the shock absorption performance of sports shoes. Many materials can be used for manufacturing soles. For example, polyvinyl chloride (PVC) which is featured by the excellent thermal stability, low price and strong abrasive resistance and has defects of poor sliding and folding resistance is not suitable for sports shoes, and moreover the production and using process of PVC may produce toxic substances [13]. Shoes whose soles are made of polyurethane (PU) are characterized by excellent durability, exercise support capacity, sliding resistance, elasticity and shock absorption performance, but the shortcomings of high risks of fracture, poor ductility and strong water absorptivity are not beneficial in the process of running [14]. Thermoplastic elastomer (TPE) has been extensively applied in the shoemaking industry because of its advantages of strong tensile and tearing strength, low-temperature resistance, air permeability and sliding resistance, but is difficult to be further promoted for its high production cost [15]. In such a case, nano-inorganic filler is needed. It can improve the mechanical performance, reduce production cost, kill bacteria and strengthen flame resistance. The objective of the paper is to test the shock absorptivity of the sports shoes which was equipped with soles that were made of nano-carbon black added TPE.

MATERIALS AND METHODS

Preparation of the Nanocarbon Black Added TPE

As the soles of running shoes available on the market do not meet experimental results, the experimental sole material was manufactured by the authors. The preparation process of the nano-carbon black added TPE [10] is shown below. The synthesized TPE glue liquor was added with anti-aging agent with a mass fraction of 1%. After even mixing, it was added with deionized water whose volume was 1/3 that of the container loaded withe the glue liquor. Next the mixture was heated in water bath at a temperature of 105°C. Then the glue was cut into pieces and dried to the constant weight in a vacuum environment at a temperature of 50°C. Then it was milled several times using a double-roll mill and added with nano-carbon black in a ratio of 1:25. After even mixing, stearic acid, zinc oxide, remaining carbon black, accelerator DM, accelerator D and antioxidant RD and sulphur. The formula used in the milling is shown in Table 2.

Table 2: The milling formula of carbon black

Ingredient	TPE	Sulphur	Antioxidant RD	Accelerator D	Accelerator DM	Zinc oxide	Stearic acid	Carbon black
Ratio/copy	100	1.9	1.1	0.5	1.3	3.9	1.5	50

The physical indexes of the nano-carbon black added TPE are shown in Table 3.

Table 3: Various physical indexes of TPE added with nano-carbon black

Item	Air permeability (mm/S)	Water absorption degree (%)	Tensile strength (MPa)	Density (mg/m^3)	Hardness (ShawW)	Compression Set (%)
Index	256	320	0.42	0.23	26	8.5
Remark			No patch			

EXPERIMENTAL

Test on the Shock Absorption Performance of Shoe Soles

Materials and Instruments

The materials were three kinds of sports shoes which were equipped with nano-carbon black added TPE sole, ordinary TPE sole and ordinary rubber sole. The sports shoes were the same in the style and size, all of them were new products.

A shock absorption test machine was used. The impactor weighed 9 kg, the diameter of the cylindrical object was 5 cm, and the head of the impactor was a hemisphere with a radius of 4 cm. The parameters were detected using the accelerometer fixed on a lead ball in the process of impact.

Test Methods

The heel part of the sole was impacted by the shock absorption test machine. The height when the impactor impacting at the sole in a static state was set as 0, and the impact energy was controlled by adjusting the height of the impactor, and the heel of the shoe sole was hit by the energy of 6 J and 10 J respectively. The impact energy was first low and then high, and 3 groups of effective impact data were collected under each impact energy, the average values were taken as the final results. The interval between the impacts was 2 min. After the impacts at two different energies completed, another pair of shoes was tested. Proper indexes were selected according to the data collected. The sports shoes showing the poorest shock absorption performance was taken as the criterion in the determination of the shock absorption performance of the soles.

RESULTS AND DISCUSSION

Analysis on the Difference of Shock Absorption Performance

The shock absorption performance of the sports shoes was measured using impact peak value and G value (the ratio of the maximum accelerated speed produced during impact to the gravitational acceleration). According to relevant regulations, the main objective of shock absorption was to reduce impact peak value and G value. Therefore smaller impact peak value and G value indicated better shock absorption performance under the same impact. Table 4 shows that the impact peak value and G value of every shoe increased with the increase of impact energy, suggesting the shock absorption of any pair of shoes was limited. The horizontal comparison of the data demonstrated that the shock absorption performance of the no. 1 shoes was the best, and that of no. 3 shoes was the poorest no matter under 6 J or 10 J, i.e. the shock absorption performance of the sports shoes which were equipped with the nano-carbon black added TPE sole was the best.

Table 4: Comparison of impact pack value and G value between different shoes under different impact energies

	Impact energy	No. 1 shoes	No. 2 shoes	No. 3 shoes
Impact peak value	6J	1872.85 N	2133.55N	2166.98N
	10J	2622.89N	2756.57N	2880.98N
G value	6J	23	25	28
	10J	32	34	37

Analysis on the Attenuation Rate of Shock Absorption Performance

It was found that the shock absorption performance of no. 3 shoes was the poorest; therefore the impact peak value of G value of no. 3 shoes were taken as the criteria. As shown in Table 5, the impact peak value and G value of no. 1 shoes were 13.57% and 17.86% lower than that of no. 3 shoes when the impact energy was 6 J; the impact peak value and G value of no. 2 shoes were 1.54% and 10.71% lower than that of no. 3 shoes. Thus it could be concluded that the shock absorption performance of no. 1 and no. 2 shoes was better than that of no. 3 shoes. The difference between no. 1 shoes and no. 3 shoes was larger. When the impact energy was 10 J, the difference changed, but the tendency was the same. Moreover the difference between no. 1 shoes and no. 2 shoes was the addition of nano-carbon black. Therefore it was concluded that the addition of nanomaterials could enhance the shock absorption performance of shoes. The vertical comparison of the differences suggested that the attenuation rate of no. 1 shoes and no. 2 shoes both decreased, indicating the shock absorption effect weakened with the increase of the impact energy.

Table 5: The comparison of no. 3 shoes with no. 1 and no. 2 shoes in the impact peak value and G value

	Impact energy	No.1 shoes	No. 2 shoes
Impact peak value	6J	-13.57%	-1.54%
	10J	-8.96%	-4.32%
G value	6J	-17.86%	-10.71%
	10J	-13.51%	-8.11%

CONCLUSION

It could be concluded that nanomaterials could improve the shock absorption performance of sports shoes. Moreover the vertical comparison of the shock absorption performance under two different impact energies suggested that the shock absorption of the soles was limited, and the shock absorption effect decreased with the increase of impact strength. In conclusion, sports shoes which are made of nanomaterials are more excellent in shock absorption compared to sports shoes which are made of ordinary materials.

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