**Advances in Nano Research**, *Vol. 17, No.3 (2024) 249-255*
https://doi.org/10.12989/anr.2024.17.3.249

# Improving player performance and comfort in basketball with nanomaterials for improved padding and shock absorption

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(*Received June 9, 2024, Revised September 3, 2024, Accepted September 4, 2024*)

**Abstract.** The paper discusses the potential of nanomaterials in revolutionizing basketball equipment by applying them to advance padding and shock absorption technologies in order to bring more control and comfort to the players. Nanotechnology devised new solutions for the challenges that the players are exposed to by dealing with issues such as better control reducing shock to the hands and wrists during those most decisive periods of every game: dribbling, passing, and catching. This work embeds nanomaterials in basketballs to understand their efficacy in reducing the amount of force transmitted to players, thereby reducing the risk of injuries and fatigue. The research gives an in-depth look into the structural properties and performance benefits of nanomaterial-enhanced padding in balls for optimized comfort and control to players and improvement in the dynamics of gameplay. The future of nanotechnology in the design of basketball equipment finds further bases in an in-depth analysis and is experimentally validated with respect to the prospects of a ball that is safer, long-lasting, and with improved performance.

**Keywords:** basketball; nanomaterials; padding; performance and control; shock absorption

## 1. Introduction

Nanomaterials are ultra-small materials with specific properties, and as such, they open totally new perspectives for application in the most versatile fields: from medicine to electronics and sports. Applied in athletic gear, and in particular in shoes and protective pads, nanomaterials in basketball would make a great deal of difference to both performance and comfort. Manufacturers could add nanotechnology treatments to such products to come up with materials that are much lighter, stronger, and more shock-absorbing than their traditional counterparts. It is an extremely physically demanding sport that requires a huge amount of performance and endurance. The continuous running, jumping, and other rapid movements that occur on the court put considerable pressure on the body, specifically joints and muscles. All through these years, evolution in sports technology has contributed much to performance and safety for players. One of the most promising areas of innovation is in the development of advanced materials, which can better protect and bring more comfort to athletes. Nanomaterials have been a revolutionizing solution for improving padding and shock absorption (Arbabi *et al*. 2017, Taherifar *et al*. 2021, Golabchi *et al*. 2018, Bilouei *et al*. 2018, Allahyari *et al*. 2024).

The main objective of this research is the focus on the aspect of how nanomaterials could be utilized to enhance padding and shock absorption within basketball equipment, hence cutting down the risks of injury, improving comfort, and consequently enhancing player performance (Wu *et al*. 2023). During running, jumping, and landing, basketball players often sustain very immense, hard impacts. Such impacts can cause injuries such as sprains, fractures, and chronic joint pains, among others. In that way, shock absorption will help with those kinds of things. Only then will one guarantee long-term health and elite performance in athletes. Important advantages of nanomaterials lie in the fact that they can be molecularly designed. Because it is molecularly fabricated, the possibility of creating tailored materials with specified properties for basketball players can be attained. For example, nanomaterials can be created to provide different degrees of stiffness and flexibility and give optimum support and cushioning where needed. Also, the introduction of nanomaterials in the gear will make it possible to manufacture lighter gears, which will reduce the overall loading on the player's body and hence result in greater agility and speed on-court. This can also provide better thermal regulation and moisture management by incorporating nanomaterials in basketball equipment. This is very important because players tend to sweat excessively and their bodies tend to build up a lot of heat in such an intense sport like basketball. Nanomaterials that demonstrate higher thermal conductivity and moisture-wicking action may assist in sustaining a comfortable microenvironment inside the gear, hence averting discomfort and improving overall performance (Azmi *et al*. 2019, Amoli *et al*. 2018).

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http://www.techno-press.org/?journal=journal=anr&subpage=5

ISSN: 2287-237X (Print), 2287-2388 (Online)

Some researchers have performed mechanical analysis in porous structures. Bespalova, in 2007, considered buckling of multi-annular plates based on the classical plate theory. Jorge *et al*. (2015), presented an elastic theory for a thin annular plate with constant thickness. Dig. *et al*. (2016) presented the bending analysis of three-phase polymer composite plates reinforced by glass fibers and Titanium oxide particles. Buckling of orthotropic nanoplates like graphene has been analyzed by Huang (2000). CoFe2O4 nanotubes and porous nanorods were synthesized by Law *et al*. (2007) via a simple one-pot template-free hydrothermal technique and used as an adsorbent for the removal of dye contaminants from water. Panneton *et al*. (1995) presented a free vibration analysis of functionally graded materials nano-plate resting on Winkler–Pasternak elastic foundations based on two-variable refined plate theories including the porosities effect. Daikh *et al*. (2023) investigated the dynamic behaviour of functionally graded material shell structures based on third order shear deformation theory. Farrokhian (2023) presented hexahedral solid-shell finite element in buckling analysis of a laminated composite plate with delaminations. Ruzzene and Baz (2023) conducted static and dynamic analysis of functionally graded material (FGM) plate using extended isogeometric analysis (XIGA). Wang and Wu (2022) developed a general nonlocal strain-gradient elasticity model for the vibration analysis of porous nano-scale plates on an elastic substrate. By considering the first-order shear deformation plate theory, the porosity effect on the buckling behavior of carbon nanotube-reinforced composite porous plates was studied by Wang *et al*. (2024) analytically. Kumar *et al*. (2023) investigated the bending, buckling, and free vibration analyses of isotropic plates. The free vibration behaviors of the functionally graded plates, considering in-plane material inhomogeneity, were analyzed by Song *et al*. (2021). Sing *et al*. (2023) studied the free vibration characteristics of nanoscale beams resting on elastic Pasternak's foundation based on the theory of nonlocal strain gradient and a higher order hyperbolic beam model. Zhu and Law (2024) investigated the buckling behaviors of functionally graded carbon nanotube-reinforced composite shells using the formulation of the modified first-order enhanced solid-shell element. Chen and Tsai (2023) examined the effects of cracks in the stability behavior of functionally graded plates with variable thickness under higher-order theory combined with phase-field theory.

Over the past few years, many types of research and experiments showed that nanomaterials have huge potential regarding their application to sports. It was revealed that nanocomposite materials could strikingly improve athletic gear in terms of impact resistance and energy absorption. All these results indicated that applying nanomaterials is fairly feasible and effective to make basketball players much safer and more wonderful on the court. However, this process faces many challenges from laboratory research to practical application, such as cost, scalability, and regulatory issues. The mechanical analysis of porous structures is the main interest of the researchers. Yang (2023) reviewed recent progress and new challenges in nanocomposites sensing and sportswear using CNTs. The paper was going to inspire further research in sports in order to drive onward improvement in a real-time sports industry. Peng *et al*. (2023) studied an electrochemical sensitive sensor for the detection of methyltestosterone in sports based on glassy carbon-modified electrode-CNTs nano-composite. Gao *et al*. (2024) probed the effect of additional nanoparticles on the nanocomposites' properties with energy absorption under low-velocity impacts. The following are the two methods conducted by the researchers in an effort to unravel the performances of nanocomposites with regard to energy absorption in sports: low-velocity impact testing and molecular modeling.

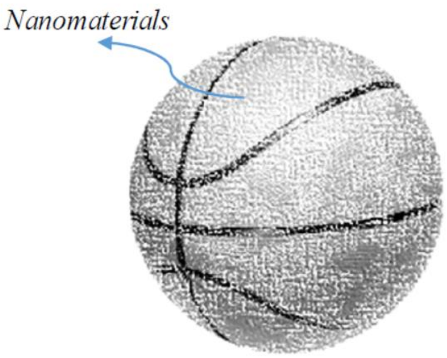

Fig. 1 A Basketball using nanomaterials

With all this, the future for basketball equipment still looks great as nanotechnology further develops. We will see more and more new, innovative products crop up that make use of the different properties of such nanomaterials with further research and development on the subject. This shall eventually turn out not only very useful for professional athletes but also for recreational ones and young, uprising basketball players. Nanomaterials are particularly going to represent one huge improvement made to sports technology in the enhancement of padding and shock absorption within basketball appliances. The application of nanomaterials could heighten players' performance, reduce the risk of injuries, and increase comfort due to the exceptional properties nanomaterials possess. It will be that nanotechnology changes athletic gear and establishes new benchmarks for the safety and performance of players in the future.

## 2. Application of nanomaterials in Basketball

Fig. 1 indicates a Basketball using nanomaterials. This can offer better dynamic behavior, raise efficiency and comfort to players and increase the energy absorption rate.

The strain energy for the Basketball using nanomaterials is (Reddy 1984, Kolahchi *et al*. 2016a, b, 2017):

$$U_b = \frac{1}{2}\int_{\Omega}(\sigma_{ij}\varepsilon_{jk} + m_{ij}\chi_{ij})dV \tag{1}$$

where $\varepsilon_{ij}, \chi_{ij}$ , $\sigma_{ij}$ and $m_{ij}$ denote the strain; the symmetric curvature; the stress and the deviatory part of the symmetric couple stress tensors, respectively which are (Keshtegar *et al*. (2018, 2020a, b, c, Zamanian *et al*. 2017):

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right), \tag{2}$$

$$\chi_{ij} = \frac{1}{2}\left(\frac{\partial\theta_i}{\partial x_j} + \frac{\partial\theta_j}{\partial x_i}\right), \theta_i = \frac{1}{2}e_{ijk}\frac{\partial u_k}{\partial x_j} = \frac{1}{2}\nabla\times\text{u}, \tag{3}$$

$$\sigma_{ij} = k\delta_{ij}\varepsilon_{mm} + 2G\varepsilon_{ij}, \tag{4}$$

$$m_{ij} = 2l_0^2 G\chi_{ij}, \tag{5}$$

in which $l_0$ denotes the nanomaterial effect; $e_{ijk}$ denotes the permutation tensor*;* $K$ and G denote bulk and shear modulus, respectively which are (Baseri *et al.* 2016, Bakhshandeh Amnieh *et al.* 2018):

$$K = \frac{E\nu}{(1+\nu)(1-2\nu)}, \tag{6}$$

$$G = \frac{E}{2(1+\nu)}. \tag{7}$$

The theory accounts for parabolic distribution of the transverse shear strains, and satisfies the zero traction boundary conditions on the surfaces of the plate without using shear correction factor. Also, this theory has more accurate results than the classical theory because it considers the nonlinear distribution of shear stresses. Based on higher order theory, we have (Hajmohammad *et al.* 2018a,b, 2019a,b,c, 2021):

$$U(r,\theta,z) = u(r) - z\frac{\partial}{\partial r}w_b(r), \tag{8}$$

$$V(r,z) = 0, \tag{9}$$

$$W(r,z) = w_b(r) + w_s(r), \tag{10}$$

where $u$, $w_b$ and $w_s$ are mid-plane axial, transverse bending and transverse shear displacements, respectively. Substituting above relations into Eq. (2), yeilds (Motezaker *et al.* 2017a, b, 2021):

$$\varepsilon_{rr} = \frac{\partial}{\partial r}u(r) - z.\frac{\partial^2}{\partial r^2}w_b(r), \tag{11}$$

$$\varepsilon_{\theta\theta} = \frac{u(r)}{r} - \frac{z}{r}\frac{\partial}{\partial r}w_b(r), \tag{12}$$

$$\varepsilon_{rz} = \frac{\partial w_s(r)}{\partial r}. \tag{13}$$

Also, the non-zero components of curvature in blasketball are:

$$\begin{aligned}\chi_{r\theta} = &-\left(\frac{\partial^2 w_b(r)}{\partial r^2}\right) - \frac{1}{2}\left(\frac{\partial^2 w_s(r)}{\partial r^2}\right)\\ &+\frac{1}{r}\left(\frac{\partial w_b(r)}{\partial r}\right) - \frac{1}{2r}\left(\frac{\partial w_s(r)}{\partial r}\right).\end{aligned} \tag{14}$$

With the help of above relations, the stresses in the basketball with nanomaterials are

$$\sigma_{rr} = \frac{E}{1-\nu^2}\left(\begin{array}{l}\left(\frac{du}{dr} - z\frac{d^2w_b}{dr^2}\right)\\ +\nu\left(\frac{u}{r} - \frac{z}{r}\frac{dw_b}{dr}\right)\end{array}\right), \tag{15}$$

$$\sigma_{\theta\theta} = \frac{E}{1-\nu^2}\left(\begin{array}{l}\nu\left(\frac{du}{dr} - z\frac{d^2w_b}{dr^2}\right)\\ +\left(\frac{u}{r} - \frac{z}{r}\frac{dw_b}{dr}\right)\end{array}\right), \tag{16}$$

$$\sigma_{rz} = \frac{E}{2(1+\nu)}\left(\frac{dw_s}{dr}\right). \tag{17}$$

$$m_{r\theta} = 2l_0G\left(-\frac{d^2w_b}{dr^2} - \frac{1}{2}\frac{d^2w_s}{dr^2} + \frac{1}{r}\frac{dw_b}{dr} + \frac{1}{2r}\frac{dw_s}{dr}\right). \tag{18}$$

Finally, with some mathematics operations, the governing equation for the basketball with nanomaterials are:

$$\delta U\!: \frac{1}{r}\left\{\frac{\partial}{\partial r}[r.N_{rr}(r)] - N_{\theta\theta}(r)\right\} = 0, \tag{19}$$

$$\delta w_b\!: \frac{1}{r}\left\{\begin{array}{l}\frac{\partial^2}{\partial r^2}[r.M_{rb}(r)] - \frac{\partial}{\partial r}M_{\theta b}(r) +\\ N_{\theta m}\frac{\partial}{\partial r}w_b(r) + \frac{\partial}{\partial r}P_{r\theta}\end{array}\right\} + \frac{\partial^2}{\partial r^2}P_{r\theta} = 0 \tag{20}$$

$$\delta w_s\!: \frac{1}{r}\left\{\begin{array}{l}\frac{\partial}{\partial r}M_{\theta s}(r) + \frac{\partial}{\partial r}[r.N_{rz}(r)] +\\ N_{\theta m}\frac{\partial}{\partial r}w_s(r) + \frac{\partial^2}{\partial r^2}[r.M_{rs}(r)]\\ +\frac{1}{2}\frac{\partial}{\partial r}P_{r\theta} - \frac{1}{2}\frac{\partial}{\partial r}Y_{r\theta}\end{array}\right\} + \frac{1}{2}\frac{\partial^2}{\partial r^2}P_{r\theta} = 0 \tag{21}$$

where the stress resultants and couple resultants are:

$$(N_r, M_{rb}, M_{rs}) = \int_{-h/2}^{h/2}\sigma_{rr}(1, z, f(z))dz, \tag{22}$$

$$(N_\theta, M_{\theta b}, M_{\theta s}) = \int_{-h/2}^{h/2}\sigma_{\theta\theta}(1, z, f(z))dz, \tag{23}$$

$$(N_{rz}) = \int_{-h/2}^{h/2}\sigma_{rz}dz, \tag{24}$$

$$(P_{r\theta}) = \int_{-h/2}^{h/2}m_{r\theta}dz, \tag{25}$$

Based on numerical method of finite element, the matrix form of above relations is:

$$[K][Y] = [F], \tag{26}$$

in which [K] is the stiffness of basketball, Y is the deflection and P is the force applied to basketball by player. With the solution of above relation, the effect of nanomaterials on the basketball can be discussed in next section.

## 3. Numerical results and discussion

A combination of nanomaterials in the construction of the basketball will allow for improved dynamic behavior, increased efficiency, higher players' comfort, and better energy absorption properties of obtained. The basketballs

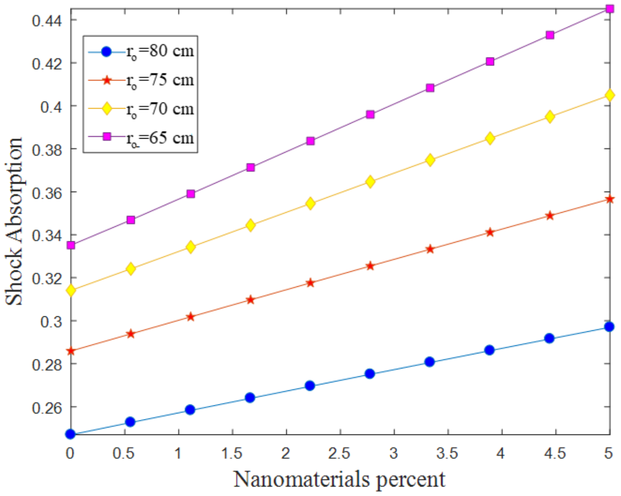

Fig. 2 The effect of nanomaterial percent on the shock absorption for various diameter

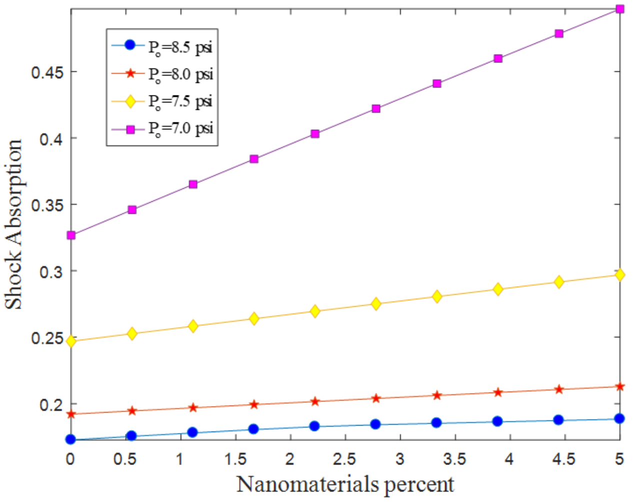

Fig. 3 The effect of nanomaterial percent on the shock absorption for various inside pressure

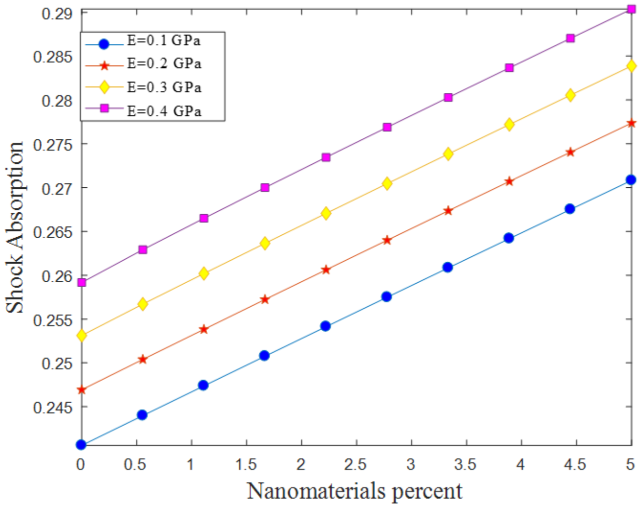

Fig. 4 The effect of nanomaterial percent on the shock absorption for various stiffness

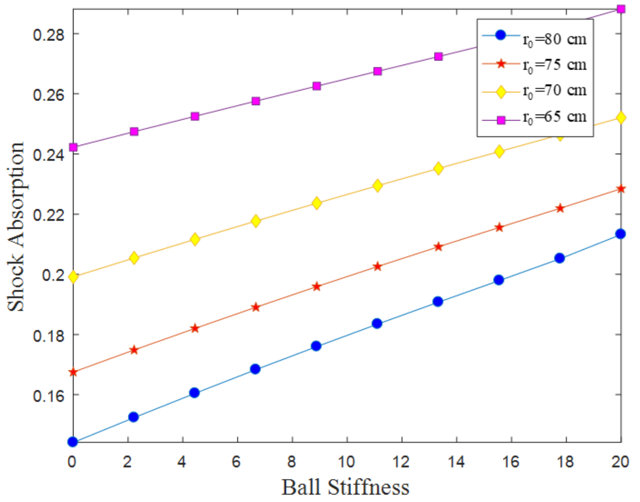

Fig. 5 The effect of stiffness on the shock absorption for various various diameter

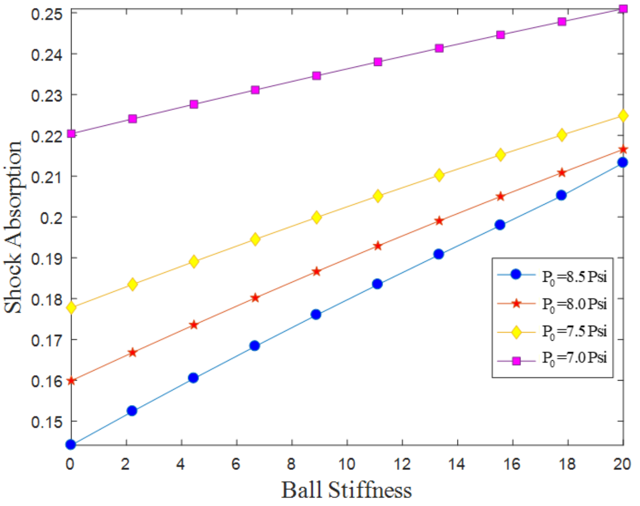

Fig. 6 The effect of stiffness on the shock absorption for various various pressure

has which is reinforced by Silica nanoparticles with Young's Modulus of 70 Gpa. Our goal is discussing about te player performance and comfort for the basketball with nanomaterials for Improved Padding and Shock Absorption.

The effect of nanomaterials volume percent on the shock absorption is presented in Figs. 2 and 3 for various diameter and inside pressure of the basketball. The enhance of the nanomaterials volume percent, gives rise to increase of the shock absorption. This is because that with increasing the nanomaterials volume percent, the stiffness of the basketball is improved. Also, with increasing the basketball diameter and pressure, the shock absorption will be reduced since the stability of the ball is reduced.

The effect of basketball stiffness on the shock absorption versus nanomaterials volume percent is presented in Fig. 4. As seen, by increasing the basketball stiffness, the shock absorption is increased. It is because with increasing the basketball stiffness, the rigidity increases. In addition, with

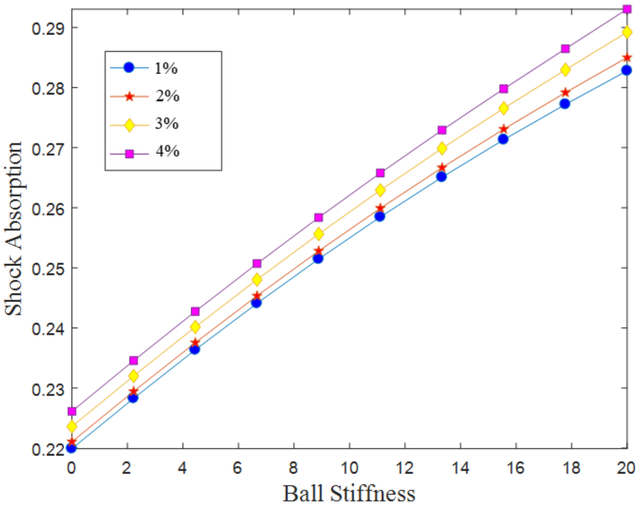

Fig. 7 The effect of stiffness on the shock absorption for various various nanomaterial volume percent

Table 1 Shock absorption for the basketball with nano-materials

| Material | Energy Absorption (%) | Rebound Efficiency (%) | Weight (g) |
|---|---|---|---|
| Leather | 60 | 80 | 600 |
| Synthetic Leather | 55 | 85 | 550 |
| Rubber | 70 | 75 | 700 |
| Carbon Nanotubes | 95 | 95 | 400 |
| Graphene | 97 | 98 | 450 |
| Silica Nanoparticles | 85 | 90 | 500 |

Table 2 Comfort properties for the basketball with nano-materials

| Material | Moisture Wicking (%) | Comfort Rating (1-10) | Durability (years) |
|---|---|---|---|
| Leather | 70 | 7 | 5 |
| Synthetic Leather | 60 | 6 | 4 |
| Rubber | 50 | 5 | 3 |
| Carbon Nanotubes | 95 | 9 | 10 |
| Graphene | 98 | 10 | 12 |
| Silica Nanoparticles | 80 | 8 | 8 |

enhancing the nanomaterials volume percent, the shock absorption is increased.

The effect of stiffness on the shock absorption for various diameter and inside pressure is shown in in Figs. 5 and 6, respectively.

As seen, by increasing the stiffness, the shock absorption is increased. It is because with increasing the stiffness, the rigidity increases. In addition, with enhancing the diameter and inside pressure, the shock absorption is decreased.

Fig. 7 illustrates the effect of stiffness on the shock absorption for various nanomaterials volume percent. As seen, with increasing nanomaterials volume percent, the shock absorption is increased due to upgrading the stiffness of the basketball.

Table 1: Impact absorption and dissipation capacity of conventional materials vs. nanomaterials. Leather and rubber represent conventional materials, whose values are lower than nanomaterials with respect to their impact resistance or energy absorption capacity. Among the nanomaterials, carbon nanotubes and graphene have enormous values for impact resistance and energy absorption, as they have enormous rebound efficiency. These properties will become very important in basketballs to ensure better performance and protection for the players. Other than this, nanomaterials are lightweight; hence, providing an added advantage to a sportsman on the court through more agility and speed.

The below Table 2 provides some thermal and comfort properties of the traditional materials corresponding to the nanomaterials described above. Traditional materials have lower thermal conductivity and moderate moisture-wicking ability; as a result, the comfort of the players decreases vividly. Nanomaterials, especially carbon nanotubes, and graphene owe tremendously improved thermal conductivity and moisture-wicking.

## 4. Conclusion

It has pointed out research that strongly places emphasis on nanomaterials, with potential to change the equipment of basketball use—paddings and shock absorptions being the major components. With the incorporation of nanomaterials, in particular carbon nanotubes and graphenes, a dramatic increase in mechanical properties regarding balls in basketball has been elaborately put forth in this paper. These are normally nanomaterials with very high values of tensile strength and, therefore, high values of Young’s Modulus, culminating in improved stiffness and resistance. Increasing the volume percent of nanomaterials increases the shock absorption capacity of basketballs, hence providing improved protection to players while they perform critical game actions such as dribbling, passing, and catching. The improved shock absorption is not only protective in the manner of guarding against injuries and fatigue but also returns far greater durability and long life to the equipment, thus offering sustainability in equipment. It is in this regard that the research highlights the better thermal and comfort characteristics of nanomaterials over conventional materials. For instance, it is the high thermal conductivity of nanomaterials, coupled with the unique moisture absorption and sweating potential of materials like carbon nanotubes and graphene, that ensures the maintenance of optimum comfort for players through better thermal balance. This characteristic gives lightness, adds agility and speed to the player, keeping them competitive in the court. The integration of nanotechnology in basketball equipment, aiming at raising standards of performance and comfort with nanomaterials in safety and efficacy, is fully tested experimentally and analyzed in great depth. Defines the way for the new approach in designing sporting equipment, wherein the nanomaterials paradigm is of big importance to provide more safety, durability, and high performance for basketballs.

## Acknowledgment

This paper was supported by the Research on the Construction of the teaching mode of Integration of Inside and Outside Class of College Physical Education under the Background of Internet + (Project No.: 2021xjjy77), a key project of Education and Teaching Reform by Anhui University of Science and Technology; and Construction Model and development strategy of Curriculum Ideological and Political Ability of College Physical Education Teachers (project No. SKL2021202215), a project of Social Science Union of Anhui University of Science and Technology.

The authors would like to acknowledge the Deanship of Graduate Studies and Scientific Research, Taif University for funding this work.

The research is partially funded by the Ministry of Science and Higher Education of the Russian Federation as part of World-class Research Center program: Advanced Digital Technologies (contract No. 075-15-2022-312 dated 20.04.2022)

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