Geomechanics and Engineering, *Vol. 32, No. 5 (2023) 463-474*
https://doi.org/10.12989/gae.2023.32.5.463

The role of nanotechnology in reducing the impact on the ball and increasing the speed of its movement

Yongyong Wang[1], Qixia Jia*[1] and Tingting Deng[2]

[1]*Ministry of Sports, Chongqing Jiaotong University, Chongqing 400074, China*
[2]*Second Foreign Language School of Sichuan Foreign Studies University, Chongqing 400074, China*

(*Received March 2, 2022, Revised February 2, 2023, Accepted February 6, 2023*)

Abstract. Materials produced with the help of new technology are used in the design of materials used in all science and engineering departments today. A sports engineering and sports equipment department is one of these departments. The use of nanotechnology in sports equipment is one of the most popular uses of this technology today. Nanomaterials have been used in sports equipment for many years, and reputable companies have benefited. Athletes' equipment allows them to display their skills to the fullest extent. It has always been a dream of professional athletes and their coaches to have unique equipment. As a result, engineers have spent all their time and effort solving this problem. Science and engineering can do various things to meet the needs of all sports levels, including specific and detailed designs, the use of appropriate materials, and standardization tests on equipment. However, these aspects must remain aligned with the latest technologies as they develop, just as with other sciences. These technologies, especially nanotechnology, are essential to sports equipment and devices developed today by sports engineers. This article examines the balls that use nanotechnology and can also improve the athlete's performance by using this technology in a specific structure. Using nanotechnology to make nanocomposite poly-hope balls, which makes them lighter and more acceptable, reduces the impact on the ball and increases its movement speed.

Keywords: ball; movement; nanomaterials; nanotechnology; sport

1. Introduction

The wide applications of nanotechnology in various products and industries have made it one of the most popular emerging branches of technology in recent years. The use of nanomaterials and products in various fields, such as agriculture, medicine, and industry, has made nanotechnology one of the pioneers of 21st-century technology (Atkuri *et al.* 2009). In sports, nanotechnology has several interesting applications, and recent developments and commercialization of products based on nanotechnology in this industry demonstrate its potential. There is no doubt that nanotechnology can be applied to sports and cover a wide range of sports fields, such as sports textiles and clothing, sports equipment, and even athlete medical equipment (Harifi and Montazer 2015). The introduction of nanotechnology has created new opportunities for developing intelligent materials that not only meet the needs of athletes but also provide them with the highest level of safety, comfort, and performance (Ćibo *et al.* 2020). Using the right equipment, athletes display their skills to their full potential. The dream of having unique equipment has always fascinated professional athletes and their coaches. In the past, it has always been a dream for professional athletes and their coaches to have unique equipment (Youtie *et al.* 2008). In the past, it has always been a dream for professional athletes and their coaches to have unique equipment. Due to this, engineers have been working on solving this problem for a long time (Gong 2013). The use of specific and detailed designs, appropriate materials, and standardization tests on equipment are all ways science and engineering can meet the needs of all sports levels. In the same way, other sciences are developing; these aspects must remain aligned with the latest developments (Singh 2016). Today, sports engineers are developing equipment and devices based on these technologies, especially nanotechnology. Many nanomaterials can be incorporated into sports equipment to improve the performance of athletes as well as their equipment. Examples include carbon nanotubes (CNTs), silica nanoparticles (SNPs), and fullerene (Patra 2013). Additionally, these nanomaterials are beneficial for sports equipment because they offer high strength, stiffness, durability, weight reduction, and wear resistance (Li 2013). Sports equipment has become lighter and stronger over the years as materials have evolved, resulting in greater strength and weight reduction (Song and Cai 2013). The specific strength and specific hardness of carbon nanotubes, a common material used in more advanced nano sports equipment, are higher than those of other common materials (Su 2014). Their strength is 100 times greater than steel, their weight is six times lighter, and their hardness is twice that of diamond, making them ideally suited for sports equipment construction, where lightness and strength are crucial. The strength and durability of CNT-containing nanocomposites are, therefore, superior to other materials commonly used in sports equipment (Zhao and Shen 2012).

---

*Corresponding author, Dr.
E-mail: 980201300018@cqjtu.edu.cn

http://www.techno-press.org/?journal=gae&subpage=7

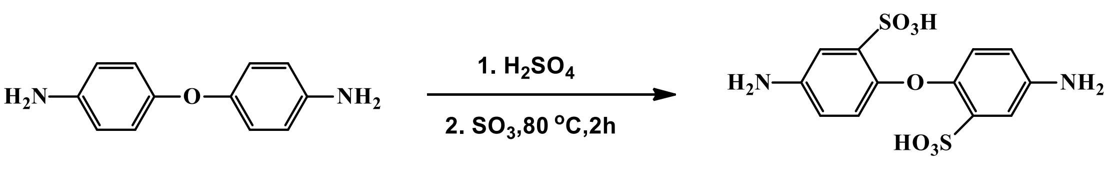
ISSN: 2005-307X (Print), 2092-6219 (Online)

For example, soccer and tennis balls coated with nano clay provide a longer-lasting pressure barrier, and nanoparticles of ZrO_2, ZnO, CuO, etc. For example, carbon nanofibers can reduce friction, wear, paint, and fracture-healing lubricants. Aerodynamic drag can be reduced, and nanotechnology can increase thermal resistance (Miah 2006). Approximately $64.9 billion worth of sports equipment was sold in 2011; by 2016, this number is expected to grow to $72.8 billion. Sports equipment for ball sports accounts for the largest share of the market (De Volder *et al.* 2013). A total of 23.7% of the value of the market is accounted for by Japan, France, Britain, Germany, and the United States, the latter accounting for 40.6%. The most popular nanomaterial in sports equipment is carbon nanotubes, widely used in golf clubs, rackets, skis, and snowboards (Rahman *et al.* 2018). Approximately 14% of the total carbon nanotube market share goes to sports equipment. There is a high probability that carbon nanotube consumption will increase rapidly shortly. The market sells better sports equipment 10-20% more durable and performs better (Sabine *et al.* 2012). Nanomaterials may be able to replace some sports equipment several times over. Although nanotechnology offers many advantages, there are not many advanced sports equipment with nanotechnology on the market due to the technology's high cost and complexity (Wang and Wang 2014).

Manufacturers need to purchase new machines to produce more advanced nano sports goods (Huang *et al.* 2006). These products are still being developed as industry personnel struggles to determine their genuine demand and how to deliver them effectively (Li *et al.* 2021, Si *et al.* 2021, Cao *et al.* 2022, Chang *et al.* 2022, Liu *et al.* 2022, Zhang *et al.* 2022). Typically, nanotechnology-enhanced sports products are more expensive on the market, making them unaffordable for most athletes (Bechthold and Weaver 2017). For nanotechnology to enhance sports performance, athletes' natural abilities must be balanced against technology. In this day and age, technology can overshadow the spirit of an athlete and their natural accomplishments.

As a result, competition might reflect the power of the technology rather than the athlete's skill if every participant does not have access to the same high-tech sports equipment (Shea 2005). As the demand for complete sports equipment has increased in recent years, investing in this sector has become increasingly necessary (Shafiei *et al.* 2016g, Ghadiri *et al.* 2017d, Shafiei *et al.* 2017d, Azimi *et al.* 2018). Competitive sports are a world where even small equipment changes can significantly impact victories and defeats. Several sports equipment manufacturers worldwide have invested heavily in nanotechnology due to the many benefits nanotechnology has shown in improving material properties (Jiang and Wang 2013). Over the last few years, carbon nanotube production has increased a lot, which is only one of the essential nanomaterials with many impressive sports applications (Ghadiri and Shafiei 2016c, Ghadiri *et al.* 2016c, Ghadiri *et al.* 2017c, Shafiei *et al.* 2017a, Shafiei *et al.* 2020). In 2007, the market value of these materials exceeded US$100 million, and this market growth rate is expected to continue. In 2007, the market value of these materials exceeded US$100 million, and the growth rate of this market is expected to continue (Meng and Zhu 2013). By 2012, the manufacturers want to increase the capacity of their production units to several thousand tons. These numbers show the scope and potential of this market. Sports applications account for 14% of the total carbon nanotube consumption, and this share is expected to increase further (Mukhopadhyay and Vinay Kumar 2008a). Many studies have been conducted to understand the impact of nanotechnology on sports equipment. Therefore, nanotechnology is seen as one of the needs of today's sports community (Chen *et al.* 2022). Sports engineers should therefore be aware of the advances in nanotechnology over the past few decades, and the importance of bringing together the latest advances and products from research and innovation in the field of nanotechnology in the world of professional sports is becoming increasingly popular (Mukhopadhyay and Vinay Kumar 2008b). All devices made with nanotechnology are designed to increase athletes' performance and prevent possible injuries. New York-based Nano Dynamics has developed an excellent add-on product for this tube (Azimi *et al.* 2016, Ghadiri and Shafiei 2016b, Ghadiri *et al.* 2017b, Shafiei *et al.* 2017b). This company has introduced a golf ball that can correct its trajectory; This means it runs straighter than regular balls. This ball does not change direction in the air at an angle of 45 degrees (Ji 2012). The ball's construction and unknown nanomaterials better direct the energy received from the golf club, preventing the ball from swinging and deflecting. These two products were ranked among the top ten nanotechnology products in the world in 2004 (Cai and Chen 2007). The Wilson company has produced a ball that has two cores. Our covers are reinforced with air, and this method is a barrier to maintaining pressure (Ghadiri *et al.* 2016a, Ebrahimi *et al.* 2017, Mirjavadi *et al.* 2017a, Mirjavadi *et al.* 2017b).

Layers of clay are added to the ball along with a liquid polymer that creates the lines inside the ball, and the clay sheets overlap each other in a parallel fashion. Because multiple layers are stacked on top of each other, each layer must force air into the bag through the other layers so the air stays inside the ball better (Rhim and Ng 2007). The nano-coating is in the second core inside the tennis ball, which is formed by spraying or rolling it on the rubber. The crust over the second core is made of stacked sheets of clay (Shafiei *et al.* 2016d, Shafiei *et al.* 2016f, Ghadiri *et al.* 2017a, Shafiei and She 2018). These plates are about one nanometer thick (Inshakova and Inshakov 2017). One of the advantages of these balls compared to ordinary balls is that they become fluffy later. The maximum time for using ordinary balls is one and a half sessions, while the maximum time for Wilson's dual-core balls is three sessions. These balls also have environmental considerations (Singh 2017). The Spalding King Ball is a lightweight option weighing just 453 grams. Although it weighs slightly more than most indoor models, the wind does not affect its trajectory as easily. This ball's composite microfiber cover is not only weather resistant but also offers a moderate level of hardness and stiffness (Shafiei *et al.* 2016c, Shafiei *et al.* 2016e, Mirjavadi *et al.* 2017d, Mousavi *et al.* 2017). Using a microfiber surface, the FLISTATEC



1

2

Scheme 1. Preparation of 4,4-diamino diphenyl ether 2,2-disulfonic acid

Molten Ball easily creates more turbulence around the ball and allows for a more direct flight. This structure allows players to apply extra power to the ball and gives the opponent little time to react (Dang *et al.* 2010). The ball has a hexagonal pattern, which is especially useful for ball defenders, and because the ball's texture offers more contact area, it is easier to hit (Davis *et al.* 2013). The Molten 5000 features flight stabilization technology to optimize airflow around the ball during flight. This increases ball visibility, essential for accurate passing and ground positioning (Ghadiri and Shafiei 2016a, Shafiei *et al.* 2016b, Shafiei and Kazemi 2017b, Shafiei *et al.* 2017c). This technology also complements the overall design by minimizing the turbulence and vibration of the ball in flight, giving the ball complete control of its movement (Handford *et al.* 2014).

Combining a composite coating and a honeycomb structure provides extra grip when your hands are sweaty. It offers excellent control, which is possible through its innovative tube relaxation structure (Zhu 2012). This patented technology allows optimal airflow between the primary and outer tubes, which maintains overall air retention and thus improves ball control. It has a perfectly balanced aerodynamic design and 18 panels that improve the ball's movement and give players more control (Wei *et al.* 2023). With increased visibility, Mikasa's new indoor ball optimizes play quality and maximizes the field's excitement. The double-dimpled microfiber surface stabilizes the ball's flight path and provides additional cushioning control. Also, the anti-sweat performance of the "Silica Nano Balloon" prevents the ball surface from slipping during intense play (Kostoff *et al.* 2006). The ball has exceeded FIVB standardization standards and passed rigorous testing protocols by leading national teams and clubs over the past six months (Omidi *et al.* 2013, Ebrahimi and Shafiei 2017, Ehyaei *et al.* 2017, Shafiei *et al.* 2019).

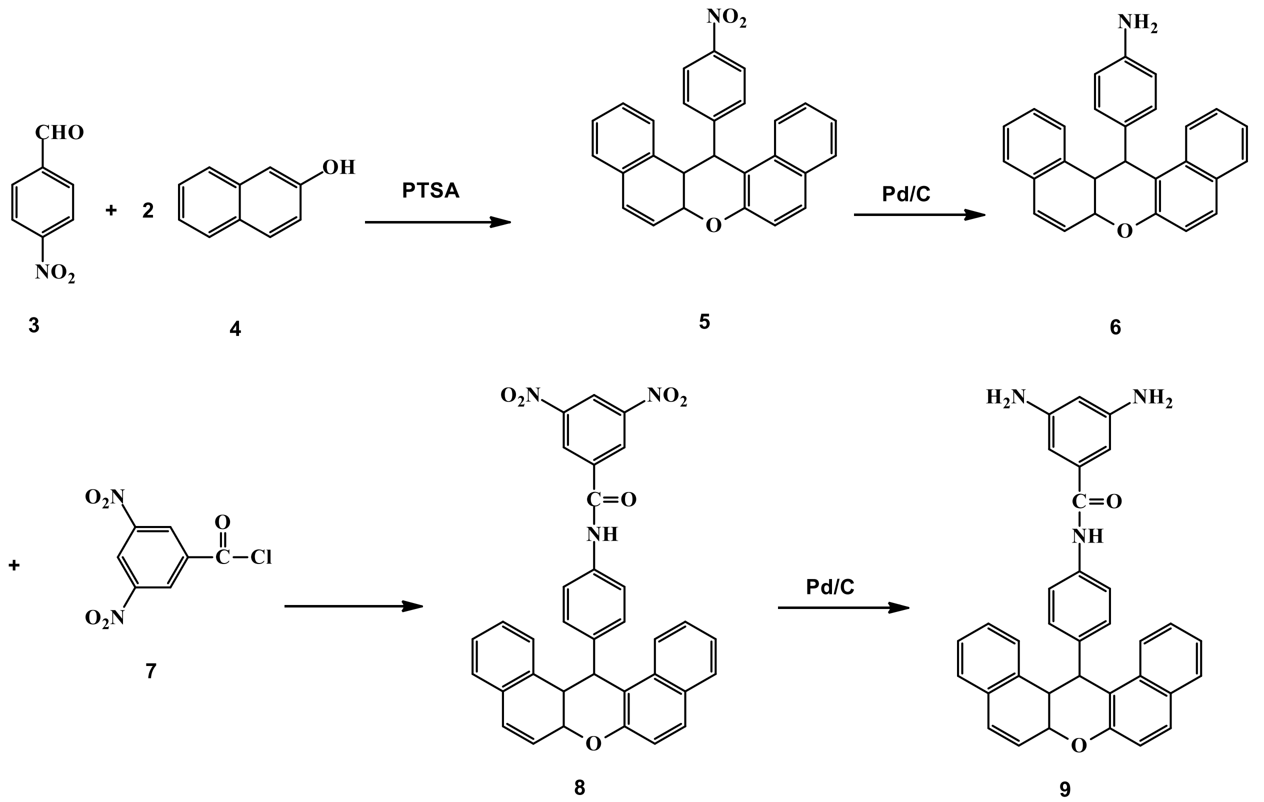
Polyimide (PI) is a polymer made from imide monomers that resist heat, freeze, flexing, and chemicals and is very light and flexible (Liaw *et al.* 2012). These polymers have a wide range of applications in various fields, e.g., in semiconductor production, electric cable coating, electronic circuits, vehicle and aircraft parts, foams, composite materials, and most notably, in the manufacture of sports equipment (Ghadiri *et al.* 2016b, Ghadiri *et al.* 2016d, Ghadiri *et al.* 2017e, Shivanian *et al.* 2017). Polyimides converted into fibers are used in the construction of sports equipment due to their high thermal, chemical, and mechanical stability and lightness (Gouzman *et al.* 2019). In this work, aromatic sulfonated polyimides are used as a factor for the lightness of the ball. Sulfonated polyimides are made by compression polymerization of dianhydride and a combination of various sulfonated and non-sulfonated diamines (Agag *et al.* 2001). In general, sulfonated polyimides exhibit high proton conductivity, good mechanical strength, and water swellability (Yano *et al.* 1997). The main problem in commercializing sulfonic polyamides is their hydrolysis to water (Hsueh and Chen 2003). To date, several methods have been proposed to strengthen the polyamide structure prior to hydrolysis, of which are the use of naphthalic dianhydrides instead of phthalic dianhydrides, the placement of sulfonic acid groups on flexible side chains, the use of flexible monomers in the sulfonated polyamide structure, and the use of playful diamines. Above and the synthesis of polyimidosulfone is fragmentary (Li *et al.* 2023).

2. Experimental

2.1 Materials and devices

In this study, compounds of 4,-4-diaminodiphenyl ether, sulfuric acid, fuming sulfuric acid, NaOH, HCl, methanol, 4-nitrobenzaldehyde, 2-naphthol, para toluene sulfonic acid, palladium/carbon 10%, ethanol, tetrahydrofuran B. dimethylacetamide, 3,5-Dinitrobenzoyl chloride, triethylamine, hydrazine monohydrate, 1,4,5,8-naphthalene tetracarboxylic anhydride, metacresol, tetraethylorthosilicate, and (3-aminopropyl)triethoxysilane manufactured by Merck. 1 H NMR spectra were recorded using a Bruker Ultrashelld 500 MHz NMR instrument. The solvent used for spectrometry was DMSO-d6. The IR spectrum was recorded with the FT-IR-680 device from JASCO. A KBr tablet was used to create this spectrum. The TEM image was recorded with a Philips CM120 device. Measurement of X-ray scattering of nanocomposites with MPD model Philips X'PERT X-ray diffraction (XRD) device with Cu A $\lambda = 1.54$ Kα in the range 2θ from 5 to 80 degrees with a scan of 0.05 degrees/min, less than 35 mA / 40 kV beam acceleration complete. Thermogravimetric analysis of the polymers was performed using the STA503 WinTA 10 instrument in a nitrogen atmosphere at a scan rate of 20°C/min. The visible-violet spectra were acquired with a 530 V JASCO UV-Vis/Near-IR instrument. The conductivity of the products was measured using an EG&G potentiostat, model PARSTAT2273 (Ebrahimi and Shafiei 2016, Shafiei *et al.* 2016a, Mirjavadi *et al.* 2017c, Shafiei and Kazemi 2017a).

2.2 Preparation of 4,4-diamino diphenyl ether 2,2-disulfonic acid (2)



Scheme 2. Preparation of diamine

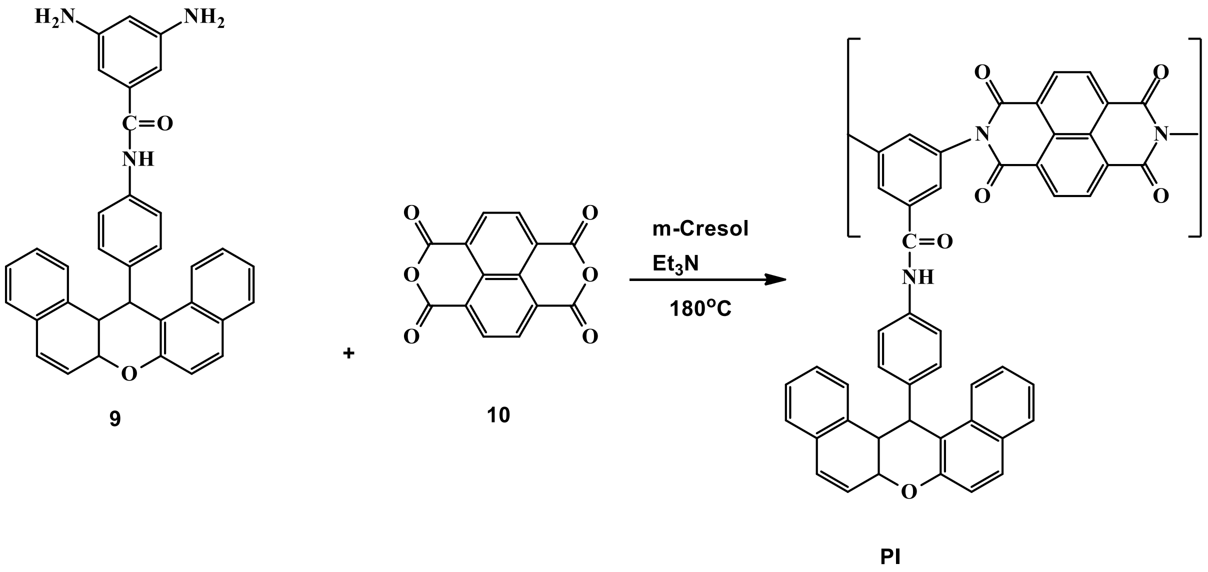
g (10-4 x 4.9 mol) of 4,4-diaminodiphenyl ether (ODA) (1) and 0.6 mL of sulfuric acid were placed in a 25 mL round bottom flask equipped with a magnetic stirrer and ice cube stirring bath at 0°C Then 1.1 ml of fuming sulfuric acid is slowly added to the reaction mixture and stirred for 3 hours under the same conditions. The reaction mixture was then stirred in an oil bath at 80°C for 2 hours. After cooling, the reaction mixture was poured into a beaker containing ice water to give a white precipitate. After that, the content of the container was filtered and the precipitate was washed with alkaline sodium hydroxide solution to dissolve the white precipitate. The resulting solution was filtered again to completely remove impurities. The resulting alkaline solution was neutralized with concentrated HCl and acidified again by increasing the acidity to form a white precipitate. The resulting precipitate was smoothed and washed with 30 mL of absolute methanol, then with 100 mL of distilled water and dried before drying (Hou *et al.* 2021, Huang *et al.* 2021b, Xu *et al.* 2021, Wang *et al.* 2022). The final yield was 0.14 grams of a white powder with a 71% reaction yield and a melting point of 269°C (Scheme 1).

2.3 Synthesis of monomer 3,5 diaminobenzoylaminophenyl-14-hydrogen dibenzo [a,j]xanthene (9)

In a 50 mL round bottom flask fitted with a magnetic stirrer, 0.1 g (1.76 x 10-4 mol) of 3,5-dinitrobenzoylaminophenyl-14-hydrogendibenzo[a,j]xanthene 0.01 g 10% is added Palladium/carbon and 15 ml of absolute ethanol were added and stirred in an oil bath at 60°C for 1 hour. Then about 3 ml of hydrazine monohydrate was added and refluxed for 12 hours. Then, 10 mL of THF was added to the reaction mixture. The reaction mixture was then refluxed for about 90 minutes (Liu *et al.* 2020b, Habibi *et al.* 2021, He *et al.* 2021, Huang *et al.* 2021a, Liu *et al.* 2021b, Zhang *et al.* 2021). The reaction mixture was then heated until palladium/carbon separated. This was filtered to form a white crystal with a melting point of 250°C and a reaction yield of 73% (Scheme 2).

2.4 Preparation of Copolyimide (CoPI)

In a 50 mL round bottom flask fitted with a magnetic stirrer, 0.1 g (10-4 x 2.7 mol) of 4,4-diaminodiphenyl-2,2-disulfonic acid ether, 2 mL of meta-cresol and 0.1 mL of triethylamine (2.4x molar ratio with diamine). The reaction mixture was stirred under nitrogen until the diamine was dissolved entirely at room temperature. Then 0.14 grams (in 2 times the molar ratio to the diamine) 1,4,5,8-naphthalene tetracarboxylic dianhydride, 0.13 grams (in the same molar ratio to the diamine) 3,5-diamino benzoyl aminophenyl-14-hydrogen dibenzo[a j]xanthene and 0.1 g (2. Benzoic acid was added to the reaction mixture in a molar ratio of 8 to diamine. The reaction mixture was stirred at room temperature for 10 minutes. It was then stirred at 100°C for 4 hours, followed by 18 hours in an oil bath at 170°C. After the reaction temperature reached 100°C, 2 ml of metacresol was added to dissolve the thick solution. Then 50 ml of acetone was added to the contents of the flask. The resulting precipitate was filtered, washed with acetone, and dried in



Scheme 3. Preparation of Copolyimide

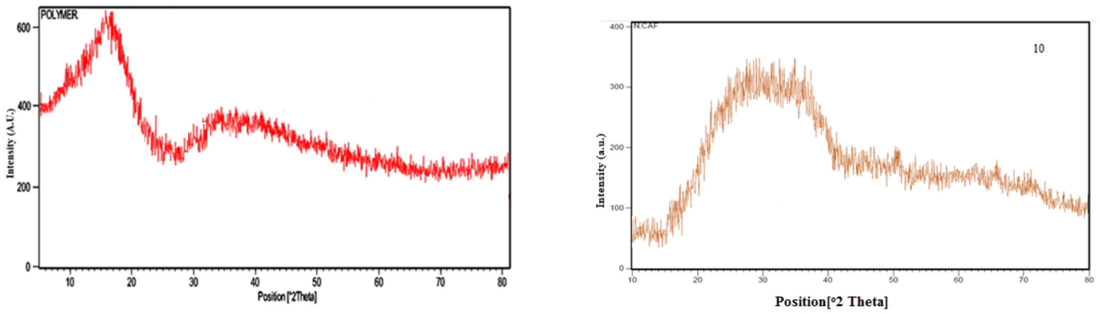


Fig. 1 X-ray diffraction pattern of nanocomposite in 10 and 20 percent by weight

an oven (Adamian *et al.* 2020, Al-Furjan *et al.* 2020a, Al-Furjan *et al.* 2020b, Li *et al.* 2020b, Zare *et al.* 2020, Dai *et al.* 2021b). Mass of copolyimide (CoPI) 0.0.30 grams yield 68%, intrinsic viscosity 0.12dl/g, and brown color (Scheme 3).

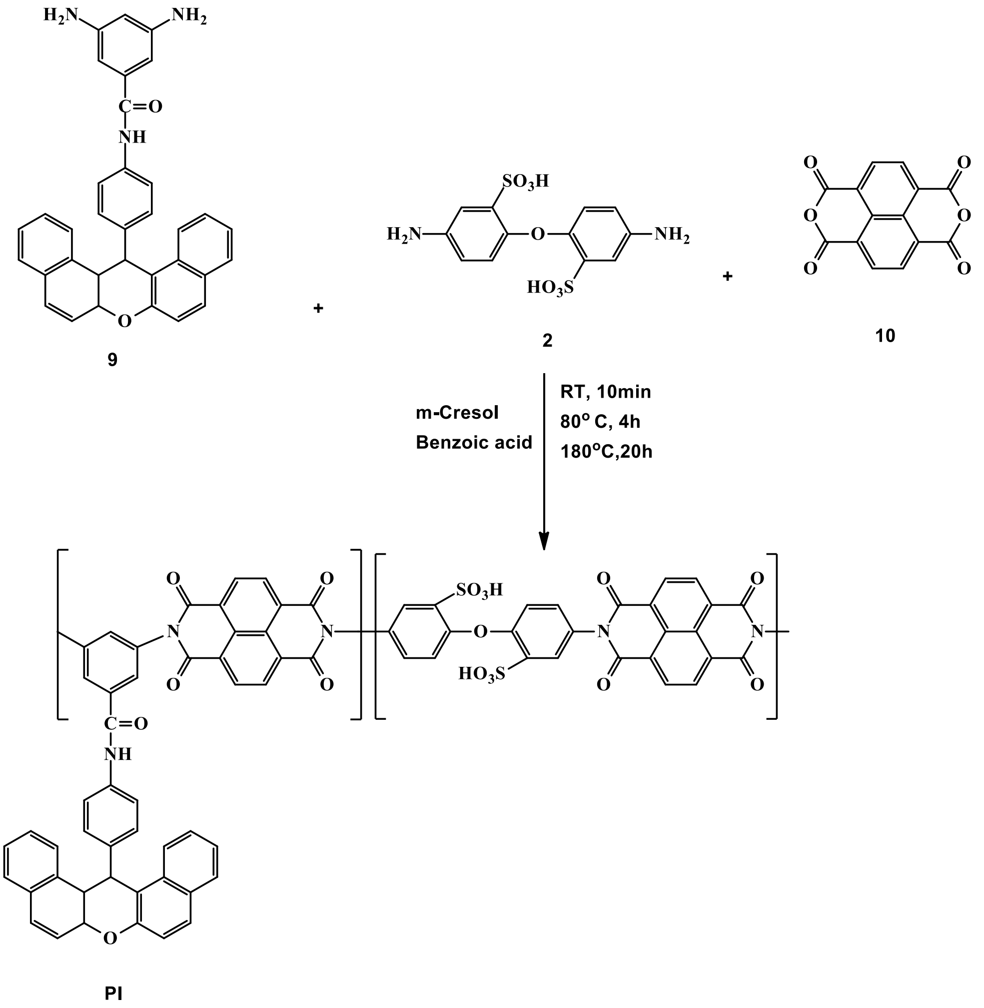
2.5 Preparation of copolyimide/silica nanocomposites by sol-gel method

0.05 g (10-10 x 9.8 mol) 3,5-diaminobenzoylaminophenyl-14 hydrogendibenzo[α,j]xanthene, 0.05 g (10-4 x 1.4 mol) 4,' 4-Diaminodiphenyl ether 2, added 2-disulfonic acid and 2 mL of N-methyl-2-pyrrolidone (NMP). The reaction mixture was stirred under nitrogen for 2 hours. After the contents of the flask were completely dissolved, the reaction mixture was stirred at room temperature for 12 hours under a nitrogen atmosphere to prepare the corresponding polyamine acid (PAA) solution. In a completely clean and dry container, a solution of tetraethyl orthosilicate (TEOS) and (3-aminopropyl)triethoxysilane (trade name KH550 in a 1:9 molar ratio) was prepared and added to the solution in the bottle and allowed to stand for 12 hours. The watch was placed under a nitrogen atmosphere. Assuming complete conversion of the tetraethyl orthosilicate reagent to silica, the amounts of this reagent were calculated such that the final silica to polymeric substrate weight ratio is 15%, 20%, and 25%. Various percentages of silica were then added to the solution and stirred for one hour. Then the resulting solution was poured into a Petri dish and placed in an oven at 80 degrees Celsius for 6 hours. The resulting nanocomposite film was placed in an oven at temperatures 140, 200, and 280 degrees Celsius for 30 minutes each to remove water molecules and produce a suitable polyamide (Al-Furjan *et al.* 2020c, Al-Furjan *et al.* 2020d, Al-Furjan *et al.* 2020f, Bai *et al.* 2020, Li *et al.* 2020a, Zhang *et al.* 2020, Guo *et al.* 2021b, Liu *et al.* 2021a). The temperature of the nanocomposite films gradually reached room temperature and was subjected to various tests (Scheme 4).

3. Discussion and conclusion

3.1 Investigation of polyimide/silica nanocomposite using X-ray diffraction (XRD)

Fig. 1 shows the X-ray diffraction pattern for nanocomposites at 10 and 20 wt%. The XRD spectrum of polyimide/silica nanocomposites shows no sharp peaks, which makes it possible to see that the prepared nanocomposites have an almost amorphous structure (Hashemi *et al.* 2019, Al-Furjan *et al.* 2020e, Cheshmeh *et al.*



Scheme 4. Preparation of copolyimide/silica nanocomposites

2020, Lori *et al.* 2020, Najaafi *et al.* 2020, Shariati *et al.* 2020). The Scherer equation calculated the average nanoparticle size to be approximately 25 nm.

3.2 Investigation of copolyimide/silica nanocomposite using a transmission electron microscope (TEM)

As a practical and valuable tool, TEM shows the size of nanoparticles and the homogeneity of nanoparticle dispersion in the polymer network. Of course, a homogeneous dispersion of nanoparticles in a polymer lattice is the best result. Fig. 2 shows a TEM image of 10% by weight. Nanocomposite. As can be seen, the nanoparticles are well dispersed in the polymer matrix. Since the particles are spherical, it can be argued that the relatively strong interaction between the polymer matrix and the silicon of the carbon dioxide nanoparticles is responsible for the spherical shape of the nanoparticles.

3.3 Gravimetric analysis (TGA) of copolyimide/silica nanocomposite

TGA was taken to test the thermal stability of the polyimide nanocomposite in the presence of SiO_2 nanoparticles. TGA results for 10 and 25-wt% silica nanocomposites were compared. The results showed that the nanocomposites' thermal stability increases with the increasing weight percentage of the nanoparticles. In addition, the carbonization efficiency of the synthesized nanocomposites is higher than that of the corresponding copolyimide types. Fig. 3 shows TGA plots of 10 and 25-wt% polyimide/silica nanocomposites.

3.4 Investigation of copolyimide/silica nanocomposite using a Scanning electron microscopy (SEM)

The SEM image shows the dimensions of nanoparticles and the uniformity of dispersion of nanoparticles in the polymer network. The morphology of the manufactured nanocomposites indicates that the nanoparticles are well dispersed in the polymer matrix. Finally, a homogeneous morphology of the polymers coated on the surface of the nanoparticles through various interactions has been created. It can be concluded that surface modification caused easier dispersion during the composite process. The average size of nanoparticles is about 40 nm. SEM images of nanocomposites with 10% by weight of ZnO nanoparticles are shown in Fig. 4.

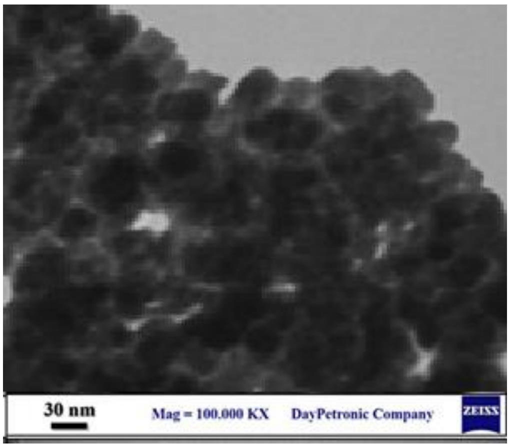


Fig. 2 TEM image of 10 wt% nanocomposite

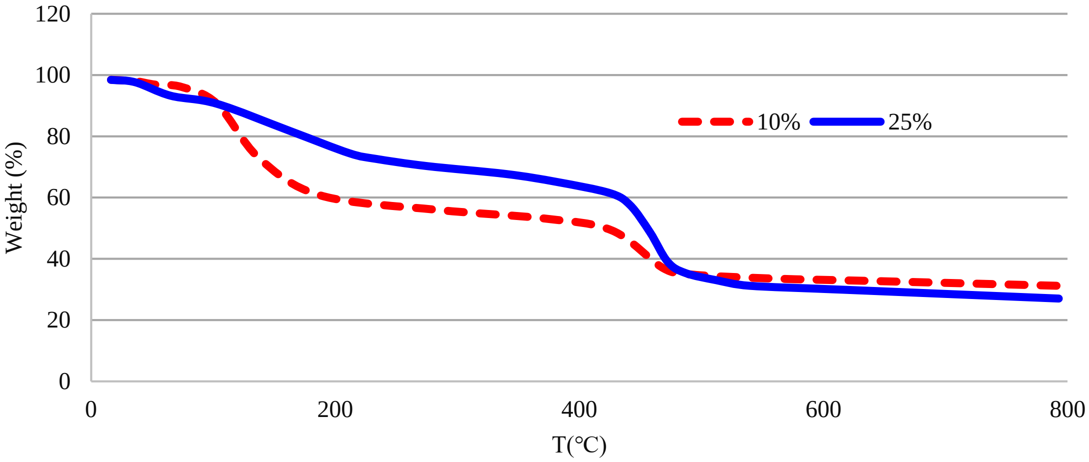


Fig. 3 TGA diagrams of 10 and 25 wt% polyamide/silica nanocomposites

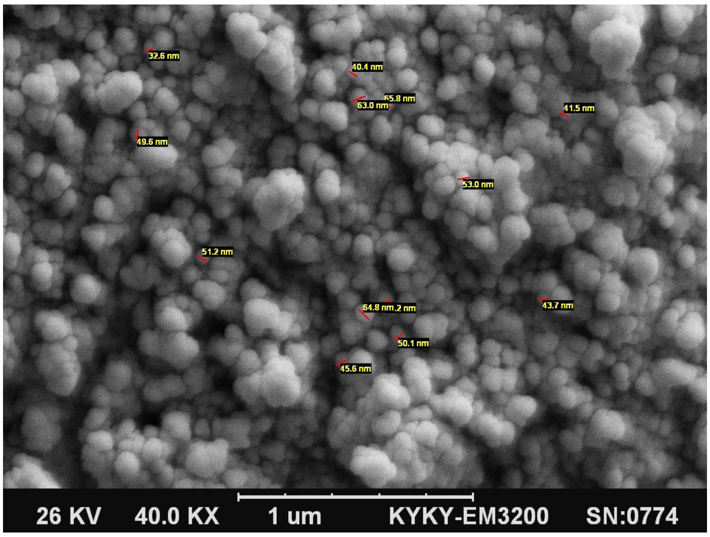


Fig. 4 SEM image of 10 wt% nanocomposite

4. Conclusions

As a revolutionary technology, Nanotechnology has impacted all areas of our daily lives, and sport is no exception. The most advanced nano sports equipment boosts performance much more than traditional sports equipment in terms of strength, hardness, and durability. Several companies are developing more innovative ideas to implement nanotechnology to improve sports equipment further. Many top athletes prefer sports equipment enriched with nanoparticles to increase their performance. Only when every worthy athlete receives similar sports gear will assessing the natural athletic ability and the human spirit will be fair and brutal. Therefore, the ultimate goal should be to push the boundaries of performance levels rather than increase the cost of high-tech exercise equipment. In addition, to manage the possible toxic problems related to nano sports equipment, it is necessary to monitor the manufacturing processes, their useful life, and their disposal to avoid the release of nanoparticles due to destruction or not. In this article, the role of nanotechnology in reducing the impact on the ball and increasing its movement speed is considered by examining the production of light polyimide. Proper distribution, nearly spherical shape of polyimide and size of nanoparticles were confirmed by TEM imaging. Investigating the thermal stability of pure copolyimide and synthesized nanocomposites showed that the thermal resistance of polyimide increases in the presence of SiO_2 nanoparticles.

References

Adamian, A., Safari, K.H., Sheikholeslami, M., Habibi, M., Al-Furjan, M. and Chen, G. (2020), “Critical temperature and frequency characteristics of GPLs-reinforced composite doubly curved panel”, *Appl. Sci.*, **10**(9), 3251. https://doi.org/10.3390/app10093251.

Agag, T., Koga, T. and Takeichi, T. (2001), “Studies on thermal and mechanical properties of polyimide–clay nanocomposites”, *Polymer*, **42**(8), 3399-3408. https://doi.org/10.1016/S0032-3861(00)00824-7.

Al-Furjan, M., Dehini, R., Khorami, M., Habibi, M. and Won Jung, D. (2020a), “On the dynamics of the ultra-fast rotating cantilever orthotropic piezoelectric nanodisk based on nonlocal strain gradient theory”, *Compos. Struct.*, 112990. https://doi.org/10.1016/j.compstruct.2020.112990.

Al-Furjan, M., Fereidouni, M., Habibi, M., Abd Ali, R., Ni, J. and Safarpour, M. (2020b), “Influence of in-plane loading on the vibrations of the fully symmetric mechanical systems via dynamic simulation and generalized differential quadrature framework”, *Eng. with Comput.*, 1-23. https://doi.org/10.1007/s00366-020-01177-7.

Al-Furjan, M., Fereidouni, M., Sedghiyan, D., Habibi, M. and Won Jung, D. (2020c), “Three-dimensional frequency response of the CNT-Carbon-Fiber reinforced laminated circular/annular plates under initially stresses”, *Compos. Struct.*, 113146. https://doi.org/10.1016/j.compstruct.2020.113146.

Al-Furjan, M., Habibi, M., won Jung, D. and Safarpour, H. (2020d), “Vibrational characteristics of a higher-order laminated composite viscoelastic annular microplate via modified couple stress theory”, *Compos. Struct.*, 113152. https://doi.org/10.1016/j.compstruct.2020.113152.

Al-Furjan, M., Moghadam, S.A., Dehini, R., Shan, L., Habibi, M. and Safarpour, H. (2020e), “Vibration control of a smart shell reinforced by graphene nanoplatelets under external load: Semi-numerical and finite element modeling”, *Thin-Wall. Struct.*, 107242. https://doi.org/10.1016/j.tws.2020.107242.

Al-Furjan, M., Oyarhossein, M.A., Habibi, M., Safarpour, H. and Jung, D.W. (2020f), “Frequency and critical angular velocity characteristics of rotary laminated cantilever microdisk via two-dimensional analysis”, *Thin-Wall. Struct.*, **157**, 107111. https://doi.org/10.1016/j.tws.2020.107111.

Atkuri, H., Cook, G., Evans, D.R., Cheon, C.I., Glushchenko, A., Reshetnyak, V., Reznikov, Y., West, J. and Zhang, K. (2009), “Preparation of ferroelectric nanoparticles for their use in liquid crystalline colloids”, *J. Opt. A: Pure Appl. Opt.*, **11**(2), 024006. https://doi.org/10.1088/1464-4258/11/2/024006.

Azimi, M., Mirjavadi, S.S., Shafiei, N. and Hamouda, A.M.S. (2016), “Thermo-mechanical vibration of rotating axially functionally graded nonlocal Timoshenko beam”, *Appl. Phys. A.* **123**(1), 104. https://doi.org/10.1007/s00339-016-0712-5.

Azimi, M., Mirjavadi, S.S., Shafiei, N., Hamouda, A.M.S. and Davari, E. (2018), “Vibration of rotating functionally graded Timoshenko nano-beams with nonlinear thermal distribution”, *Mech. Adv. Mater. Struct.*, **25**(6), 467-480. https://doi.org/10.1080/15376494.2017.1285455.

Bai, Y., Alzahrani, B., Baharom, S. and Habibi, M. (2020), “Semi-numerical simulation for vibrational responses of the viscoelastic imperfect annular system with honeycomb core under residual pressure”, *Eng. with Comput.*, 1-26. https://doi.org/10.1007/s00366-020-01191-9.

Bechthold, M. and Weaver, J.C. (2017), “Materials science and architecture”, *Nature Rev. Mater.*, **2**(12), 17082. https://doi.org/10.1038/natrevmats.2017.82.

Cai, W. and Chen, X. (2007), “Nanoplatforms for Targeted Molecular Imaging in Living Subjects”, *Small.*, **3**(11), 1840-1854. https://doi.org/10.1002/smll.200700351.

Cao, C., Wang, J., Kwok, D., Cui, F., Zhang, Z., Zhao, D., Li, M.J. and Zou, Q. (2022), “webTWAS: a resource for disease candidate susceptibility genes identified by transcriptome-wide association study”, *Nucleic Acids Res.*, **50**(1), 1123-1130. https://doi.org/10.1093/nar/gkab957.

Chang, Y., Niu, B., Wang, H., Zhang, L., Ahmad, A.M. and Alassafi, M.O. (2022), “Adaptive tracking control for nonlinear system in pure-feedback form with prescribed performance and unknown hysteresis”, *IMA J. Math. Control Inform.*, **39**(3), 892-911. https://doi.org/10.1093/imamci/dnac015.

Chen, P., Pei, J., Lu, W. and Li, M. (2022), “A deep reinforcement learning based method for real-time path planning and dynamic obstacle avoidance”, *Neurocomput.*, **497** 64-75. https://doi.org/10.1016/j.neucom.2022.05.006.

Cheshmeh, E., Karbon, M., Eyvazian, A., Jung, D.W., Habibi, M. and Safarpour, M. (2020), “Buckling and vibration analysis of FG-CNTRC plate subjected to thermo-mechanical load based on higher order shear deformation theory”, *Mech. Based Des. Struct. Mach.*, 1-24. https://doi.org/10.1080/15397734.2020.1744005.

Ćibo, M., Šator, A., Kazlagić, A. and Omanović-Mikličanin, E. (2020). “Application and Impact of Nanotechnology in Sport”, *Proceedings of the 30th Scientific-Experts Conference of Agriculture and Food Industry*, Cham..

Dai, Z., Jiang, Z., Zhang, L. and Habibi, M. (2021a), “Frequency characteristics and sensitivity analysis of a size-dependent laminated nanoshell”, *Adv. Nano Res.*, **10**(2), 175-189. https://doi.org/10.12989/anr.2021.10.2.175.

Dai, Z., Zhang, L., Bolandi, S.Y. and Habibi, M. (2021b), “On the vibrations of the non-polynomial viscoelastic composite open-type shell under residual stresses”, *Compos. Struct.*, 113599. https://doi.org/10.1016/j.compstruct.2021.113599.

Dang, Y., Zhang, Y., Fan, L., Chen, H. and Roco, M.C. (2010), “Trends in worldwide nanotechnology patent applications: 1991 to 2008”, *J. Nanoparticle Res.*, **12**(3), 687-706. https://doi.org/10.1007/s11051-009-9831-7.

Davis, D., Guo, X., Musavi, L., Lin, C.S., Chen, S.H. and Wu, V.C.H. (2013), “Gold nanoparticle-modified carbon electrode biosensor for the detection of listeria monocytogenes”, *Ind. Biotechnol.*, **9**(1), 31-36. https://doi.org/10.1089/ind.2012.0033.

De Volder, M.F.L., Tawfick, S.H., Baughman, R.H. and Hart, A.J. (2013), “Carbon nanotubes: Present and future commercial applications”, *Science*, **339**(6119), 535-539. https://doi.org/10.1126/science.1222453.

Ebrahimi, F. and Shafiei, N. (2016), “Application of Eringen's nonlocal elasticity theory for vibration analysis of rotating functionally graded nanobeams”, *Smart Struct. Syst.*, **17**(5), 837-857. https://doi.org/10.12989/sss.2016.17.5.837.

Ebrahimi, F. and Shafiei, N. (2017), “Influence of initial shear stress on the vibration behavior of single-layered graphene sheets embedded in an elastic medium based on Reddy's higher-order shear deformation plate theory”, *Mech. Adv. Mater. Struct.*, **24**(9), 761-772. https://doi.org/10.1080/15376494.2016.1196781.

Ebrahimi, F., Shafiei, N., Kazemi, M. and Mousavi Abdollahi, S.M. (2017), “Thermo-mechanical vibration analysis of rotating nonlocal nanoplates applying generalized differential quadrature method”, *Mech. Adv. Mater. Struct.*, **24**(15), 1257-1273. https://doi.org/10.1080/15376494.2016.1227499.

Ehyaei, J., Akbarshahi, A. and Shafiei, N. (2017), “Influence of porosity and axial preload on vibration behavior of rotating FG nanobeam”, *Adv. Nano Res.*, **5**(2), 141-169. https://doi.org/10.12989/anr.2017.5.2.141.

Ghadiri, M., Hosseini, S.H.S. and Shafiei, N. (2016a), “A power series for vibration of a rotating nanobeam with considering thermal effect”, *Mech. Adv. Mater. Struct.*, **23**(12), 1414-1420. https://doi.org/10.1080/15376494.2015.1091527.

Ghadiri, M., Mahinzare, M., Shafiei, N. and Ghorbani, K. (2017a), “On size-dependent thermal buckling and free vibration of circular FG Microplates in thermal environments”, *Microsyst. Technologies*, **23**(10), 4989-5001. https://doi.org/10.1007/s00542-017-3308-x.

Ghadiri, M. and Shafiei, N. (2016a), “Nonlinear bending vibration of a rotating nanobeam based on nonlocal Eringen’s theory using differential quadrature method”, *Microsyst. Technologies*, **22**(12), 2853-2867. https://doi.org/10.1007/s00542-015-2662-9.

Ghadiri, M. and Shafiei, N. (2016b), “Vibration analysis of a nano-turbine blade based on Eringen nonlocal elasticity applying the differential quadrature method”, *J. Vib. Control*, **23**(19), 3247-3265. https://doi.org/10.1177/1077546315627723.

Ghadiri, M. and Shafiei, N. (2016c), “Vibration analysis of rotating functionally graded Timoshenko microbeam based on modified couple stress theory under different temperature distributions”, *Acta Astronautica*, **121**, 221-240. https://doi.org/10.1016/j.actaastro.2016.01.003.

Ghadiri, M., Shafiei, N. and Akbarshahi, A. (2016b), “Influence of thermal and surface effects on vibration behavior of nonlocal rotating Timoshenko nanobeam”, *Appl. Phys. A.*, **122**(7), 673. https://doi.org/10.1007/s00339-016-0196-3.

Ghadiri, M., Shafiei, N. and Alavi, H. (2017b), “Thermo-mechanical vibration of orthotropic cantilever and propped cantilever nanoplate using generalized differential quadrature method”, *Mech. Adv. Mater. Struct.*, **24**(8), 636-646. https://doi.org/10.1080/15376494.2016.1196770.

Ghadiri, M., Shafiei, N. and Alavi, H. (2017c), “Vibration analysis of a rotating nanoplate using nonlocal elasticity theory”, *J. Solid Mech.*, **9**(2), 319-337. 20.1001.1.20083505.2017.9.2.8.5.

Ghadiri, M., Shafiei, N. and Alireza Mousavi, S. (2016c), “Vibration analysis of a rotating functionally graded tapered microbeam based on the modified couple stress theory by DQEM”, *Appl. Phys. A.*, **122**(9), 837. https://doi.org/10.1007/s00339-016-0364-5.

Ghadiri, M., Shafiei, N. and Babaei, R. (2017d), “Vibration of a rotary FG plate with consideration of thermal and Coriolis effects”, *Steel Compos. Struct.*, **25**(2), 197-207. https://doi.org/10.12989/scs.2017.25.2.197.

Ghadiri, M., Shafiei, N. and Safarpour, H. (2017e), “Influence of surface effects on vibration behavior of a rotary functionally graded nanobeam based on Eringen’s nonlocal elasticity”, *Microsyst. Technologies*, **23**(4), 1045-1065. https://doi.org/10.1007/s00542-016-2822-6.

Ghadiri, M., Shafiei, N., Salekdeh, S.H., Mottaghi, P. and Mirzaie, T. (2016d), “Investigation of the dental implant geometry effect on stress distribution at dental implant–bone interface”, *J. Braz. Soc. Mech. Sci. Eng.*, **38**(2), 335-343. https://doi.org/10.1007/s40430-015-0472-8.

Gong, Z.G. (2013), “Nanotechnology application in sports”, *Adv. Mater. Res.*, **662**, 186-189. https://doi.org/10.4028/www.scientific.net/AMR.662.186.

Gouzman, I., Grossman, E., Verker, R., Atar, N., Bolker, A. and Eliaz, N. (2019), “Advances in polyimide-based materials for space applications”, *Adv. Mater.*, **31**(18), 1807738. https://doi.org/10.1002/adma.201807738.

Guo, J., Baharvand, A., Tazeddinova, D., Habibi, M., Safarpour, H., Roco-Videla, A. and Selmi, A. (2021a), “An intelligent computer method for vibration responses of the spinning multi-layer symmetric nanosystem using multi-physics modeling”, *En. with Comput.*, 1-22. https://doi.org/10.1007/s00366-021-01433-4.

Guo, Y., Mi, H. and Habibi, M. (2021b), “Electromechanical energy absorption, resonance frequency, and low-velocity impact analysis of the piezoelectric doubly curved system”, *Mech. Syst. Signal Pr.*, **157**, 107723. https://doi.org/10.1016/j.ymssp.2021.107723.

Habibi, M., Darabi, R., Sa, J.C.D. and Reis, A. (2021), “An innovation in finite element simulation via crystal plasticity assessment of grain morphology effect on sheet metal formability”, *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*. **235**(8), 1937-1951. https://doi.org/10.1177/14644207211024686.

Handford, C.E., Dean, M., Henchion, M., Spence, M., Elliott, C.T. and Campbell, K. (2014), “Implications of nanotechnology for the agri-food industry: Opportunities, benefits and risks”, *Trends in Food Sci. Technol.*, **40**(2), 226-241. https://doi.org/10.1016/j.tifs.2014.09.007.

Harifi, T. and Montazer, M. (2015), “Application of nanotechnology in sports clothing and flooring for enhanced sport activities, performance, efficiency and comfort: a review”, *J. Ind. Textiles*, **46**(5), 1147-1169. https://doi.org/10.1177/1528083715601512.

Hashemi, H.R., Alizadeh, A.A., Oyarhossein, M.A., Shavalipour, A., Makkiabadi, M. and Habibi, M. (2019), “Influence of imperfection on amplitude and resonance frequency of a reinforcement compositionally graded nanostructure”, *Waves in Random Complex Media*, 1-27. https://doi.org/10.1080/17455030.2019.1662968.

He, X., Ding, J., Habibi, M., Safarpour, H. and Safarpour, M. (2021), “Non-polynomial framework for bending responses of the multi-scale hybrid laminated nanocomposite reinforced circular/annular plate”, *Thin-Wall. Struct.*, **166**, 108019. https://doi.org/10.1016/j.tws.2021.108019.

Hou, F., Wu, S., Moradi, Z. and Shafiei, N. (2021), “The computational modeling for the static analysis of axially functionally graded micro-cylindrical imperfect beam applying the computer simulation”, *Eng. with Comput.*, 1-19. https://doi.org/10.1007/s00366-021-01456-x.

Hsueh, H.B. and Chen, C.Y. (2003), “Preparation and properties of LDHs/polyimide nanocomposites”, *Polymer*, **44**(4), 1151-1161. https://doi.org/10.1016/S0032-3861(02)00887-X.

Huang, J.Y., Chen, S., Wang, Z.Q., Kempa, K., Wang, Y.M., Jo, S.H., Chen, G., Dresselhaus, M.S. and Ren, Z.F. (2006), “Superplastic carbon nanotubes”, *Nature*, **439**(7074), 281-281. https://doi.org/10.1038/439281a.

Huang, X., Hao, H., Oslub, K., Habibi, M. and Tounsi, A. (2021a), “Dynamic stability/instability simulation of the rotary size-dependent functionally graded microsystem”, *Eng. with Comput.*, 1-17. https://doi.org/10.1007/s00366-021-01399-3.

Huang, X., Zhang, Y., Moradi, Z. and Shafiei, N. (2021b), "Computer simulation via a couple of homotopy perturbation methods and the generalized differential quadrature method for nonlinear vibration of functionally graded non-uniform micro-tube", *Eng. with Comput.*, 1-18. https://doi.org/10.1007/s00366-021-01395-7.

Inshakova, E. and Inshakov, O. (2017), "World market for nanomaterials: structure and trends", *MATEC Web Conf.*, **129**. https://doi.org/10.1051/matecconf/201712902013.

Ji, Y. (2012), "The Applied Research of Nano-Material in Athletic Facilities and Sports Equipments", *Adv. Mater. Res.*, **459** 398-401. https://doi.org/10.4028/www.scientific.net/AMR.459.398.

Jiang, Y.P. and Wang, Y.X. (2013), "Study of Sport Devices Based on Nanomaterial", *Appl. Mech. Mater.*, **329** 75-78. https://doi.org/10.4028/www.scientific.net/AMM.329.75.

Kostoff, R.N., Stump, J.A., Johnson, D., Murday, J.S., Lau, C.G.Y. and Tolles, W.M. (2006), "The structure and infrastructure of the global nanotechnology literature", *J. Nanoparticle Res.*, **8**(3), 301-321. https://doi.org/10.1007/s11051-005-9035-8.

Li, B.F. (2013), "Design of Sports Field Based on Nanometer Materials", *Appl. Mech. Mater.*, **340**, 366-369. https://doi.org/10.4028/www.scientific.net/AMM.340.366.

Li, J., Tang, F. and Habibi, M. (2020a), "Bi-directional thermal buckling and resonance frequency characteristics of a GNP-reinforced composite nanostructure", *Eng. with Comput.*, 1-22. https://doi.org/10.1007/s00366-020-01110-y.

Li, P., Yang, M. and Wu, Q. (2021), "Confidence interval based distributionally robust real-time economic dispatch approach considering wind power accommodation risk", *IEEE T. Sust. Energy*, **12**(1), 58-69. https://doi.org/10.1109/TSTE.2020.2978634.

Li, R., Liu, Z., Chen, R. and Guo, S. (2023), "In-situ fabrication of polyimide microphase and its effects on the mechanical and dielectric properties of polytetrafluoroethylene composite films", *Compos. Part A: Appl. Sci. Manuf.*, **166**, 107381. https://doi.org/10.1016/j.compositesa.2022.107381.

Li, Y., Li, S., Guo, K., Fang, X. and Habibi, M. (2020b), "On the modeling of bending responses of graphene-reinforced higher order annular plate via two-dimensional continuum mechanics approach", *Eng. with Comput.*, 1-22. https://doi.org/10.1007/s00366-020-01166-w.

Liaw, D.J., Wang, K.L., Huang, Y.C., Lee, K.R., Lai, J.Y. and Ha, C.S. (2012), "Advanced polyimide materials: Syntheses, physical properties and applications", *Progress in Polymer Sci.*, **37**(7), 907-974. https://doi.org/10.1016/j.progpolymsci.2012.02.005.

Liu, H., Shen, S., Oslub, K., Habibi, M. and Safarpour, H. (2021a), "Amplitude motion and frequency simulation of a composite viscoelastic microsystem within modified couple stress elasticity", *Eng. with Comput.*, 1-15. https://doi.org/10.1007/s00366-021-01316-8.

Liu, H., Zhao, Y., Pishbin, M., Habibi, M., Bashir, M. and Issakhov, A. (2021b), "A comprehensive mathematical simulation of the composite size-dependent rotary 3D microsystem via two-dimensional generalized differential quadrature method", *Eng. with Comput.*, 1-16. https://doi.org/10.1007/s00366-021-01419-2.

Liu, S., Niu, B., Zong, G., Zhao, X. and Xu, N. (2022), "Adaptive fixed-time hierarchical sliding mode control for switched under-actuated systems with dead-zone constraints via event-triggered strategy", *Appl. Math. Comput.*, **435**, 127441. https://doi.org/10.1016/j.amc.2022.127441.

Liu, Z., Su, S., Xi, D. and Habibi, M. (2020a), "Vibrational responses of a MHC viscoelastic thick annular plate in thermal environment using GDQ method", *Mech. Based Des. Struct. Mach.*, 1-26. https://doi.org/10.1080/15397734.2020.1784201.

Liu, Z., Wu, X., Yu, M. and Habibi, M. (2020b), "Large-amplitude dynamical behavior of multilayer graphene platelets reinforced nanocomposite annular plate under thermo-mechanical loadings", *Mech. Based Des. Struct. Mach.*, 1-25. https://doi.org/10.1080/15397734.2020.1815544.

Lori, E.S., Ebrahimi, F., Supeni, E.E.B., Habibi, M. and Safarpour, H. (2020), "The critical voltage of a GPL-reinforced composite microdisk covered with piezoelectric layer", *Eng. with Comput.*, 1-20. https://doi.org/10.1007/s00366-020-01004-z.

Meng, Y.L. and Zhu, J.Q. (2013), "Application of Nanomaterial in Sports and its Safety Research", *Appl. Mech. Mater.*, **387** 36-39. https://doi.org/10.4028/www.scientific.net/AMM.387.36.

Miah, A. (2006), "Rethinking Enhancement in Sport", *Annal. New York Academy Sci.*, **1093**(1), 301-320. https://doi.org/10.1196/annals.1382.020.

Mirjavadi, S.S., Afshari, B.M., Shafiei, N., Hamouda, A., Kazemi, M. and Structures, C. (2017a), "Thermal vibration of two-dimensional functionally graded (2D-FG) porous Timoshenko nanobeams", *Steel Compos. Struct.*, **25**(4), 415-426. https://doi.org/10.12989/scs.2017.25.4.415.

Mirjavadi, S.S., Matin, A., Shafiei, N., Rabby, S. and Mohasel Afshari, B. (2017b), "Thermal buckling behavior of two-dimensional imperfect functionally graded microscale-tapered porous beam", *J. Therm. Stresses*, **40**(10), 1201-1214. https://doi.org/10.1080/01495739.2017.1332962.

Mirjavadi, S.S., Mohasel Afshari, B., Shafiei, N., Rabby, S. and Kazemi, M. (2017c), "Effect of temperature and porosity on the vibration behavior of two-dimensional functionally graded micro-scale Timoshenko beam", *J. Vib. Control.*, **24**(18), 4211-4225. https://doi.org/10.1177/1077546317721871.

Mirjavadi, S.S., Rabby, S., Shafiei, N., Afshari, B.M. and Kazemi, M. (2017d), "On size-dependent free vibration and thermal buckling of axially functionally graded nanobeams in thermal environment", *Appl. Phys. A.*, **123**(5), 315. https://doi.org/10.1007/s00339-017-0918-1.

Mousavi, S.M., Shafiei, N. and Dadvand, A. (2017), "Numerical simulation of subsonic turbulent flow over NACA0012 airfoil: evaluation of turbulence models", *Sigma J. Eng. Nat. Sci.*, **35**(1), 133-155. https://dergipark.org.tr/en/pub/sigma/issue/65585/1016455#article_cite.

Mukhopadhyay, A. and Vinay Kumar, M. (2008a), "A review on designing the waterproof breathable fabrics Part I: Fundamental principles and designing aspects of breathable fabrics", *J. Ind. Textiles*, **37**(3), 225-262. https://doi.org/10.1177/1528083707082164.

Mukhopadhyay, A. and Vinay Kumar, M. (2008b), "A Review on Designing the Waterproof Breathable Fabrics Part II: Construction and Suitability of Breathable Fabrics for Different Uses", *J. Ind. Textiles*, **38**(1), 17-41. https://doi.org/10.1177/1528083707082166.

Najaafi, N., Jamali, M., Habibi, M., Sadeghi, S., Jung, D.W. and Nabipour, N. (2020), "Dynamic instability responses of the substructure living biological cells in the cytoplasm environment using stress-strain size-dependent theory", *J. Biomol. Struct. Dyn.*, 1-12. https://doi.org/10.1080/07391102.2020.1751297.

Omidi, S., Oskooee, M.B. and Shafiei, N. (2013), "Finite element analysis of an ultra-fine grained Titanium dental implant covered by different thicknesses of hydroxyapatite layer", *Indian J. Dentistry*, **4**(1), 1-4. https://doi.org/10.1016/j.ijd.2012.10.002.

Patra, J.K. (2013), "Application of nanotechnology in textile engineering: An overview", *J. Eng. Technol. Res.*, **5**, 104-111. https://doi.org/10.5897/JETR2013.0309.

Rahman, M.M., Hussein, M.A., Alamry, K.A., Al-Shehry, F.M. and Asiri, A.M. (2018), "Polyaniline/graphene/carbon nanotubes nanocomposites for sensing environmentally hazardous 4-aminophenol", *Nano-Structures & Nano-Objects*. **15**, 63-74. https://doi.org/10.1016/j.nanoso.2017.08.006.

Rhim, J.W. and Ng, P.K.W. (2007), "Natural biopolymer-based nanocomposite films for packaging applications", *Critical Reviews in Food Science and Nutrition*, **47**(4), 411-433. https://doi.org/10.1080/10408390600846366.

Sabine, G.l., René, F. and Myrtill, S. (2012), Carbon nanotubes–part I: Introduction, production, areas of application (NanoTrust Dossier No. 022en–February 2012), Eigenverlag/Self-published, Wien. https://doi.org/10.1553/ITA-nt-022en.

Shafiei, N., Ghadiri, M. and Mahinzare, M. (2019), "Flapwise bending vibration analysis of rotary tapered functionally graded nanobeam in thermal environment", *Mech. Adv. Mater. Struct*., **26**(2), 139-155. https://doi.org/10.1080/15376494.2017.1365982.

Shafiei, N., Ghadiri, M., Makvandi, H. and Hosseini, S.A. (2017a), "Vibration analysis of Nano-Rotor's Blade applying Eringen nonlocal elasticity and generalized differential quadrature method", *Appl. Math. Model*., **43**, 191-206. https://doi.org/10.1016/j.apm.2016.10.061.

Shafiei, N., Hamisi, M. and Ghadiri, M. (2020), "Vibration analysis of rotary tapered axially functionally graded Timoshenko nanobeam in thermal environment", *J. Solid Mech.*, **12**(1), 16-32. 20.1001.1.20083505.2020.12.1.2.8.

Shafiei, N. and Kazemi, M. (2017a), "Buckling analysis on the bi-dimensional functionally graded porous tapered nano-/micro-scale beams", *Aerosp. Sci. Technol*., **66**, 1-11. https://doi.org/10.1016/j.ast.2017.02.019.

Shafiei, N. and Kazemi, M. (2017b), "Nonlinear buckling of functionally graded nano-/micro-scaled porous beams", *Compos. Struct.*, **178**, 483-492. https://doi.org/10.1016/j.compstruct.2017.07.045.

Shafiei, N., Kazemi, M. and Fatahi, L. (2017b), "Transverse vibration of rotary tapered microbeam based on modified couple stress theory and generalized differential quadrature element method", *Mech. Adv. Mater. Struct.*, **24**(3), 240-252. https://doi.org/10.1080/15376494.2015.1128025.

Shafiei, N., Kazemi, M. and Ghadiri, M. (2016a), "Comparison of modeling of the rotating tapered axially functionally graded Timoshenko and Euler–Bernoulli microbeams", *Physica E: Low-dimensional Syst. Nanostruct.*, **83**, 74-87. https://doi.org/10.1016/j.physe.2016.04.011.

Shafiei, N., Kazemi, M. and Ghadiri, M. (2016b), "Nonlinear vibration behavior of a rotating nanobeam under thermal stress using Eringen's nonlocal elasticity and DQM", *Appl. Phys. A.*, **122**(8), 728. https://doi.org/10.1007/s00339-016-0245-y.

Shafiei, N., Kazemi, M. and Ghadiri, M. (2016c), "Nonlinear vibration of axially functionally graded tapered microbeams", *Int. J. Eng. Sci.*, **102**, 12-26. https://doi.org/10.1016/j.ijengsci.2016.02.007.

Shafiei, N., Kazemi, M. and Ghadiri, M. (2016d), "On size-dependent vibration of rotary axially functionally graded microbeam", *Int. J. Eng. Sci.*, **101**, 29-44. https://doi.org/10.1016/j.ijengsci.2015.12.008.

Shafiei, N., Kazemi, M., Safi, M. and Ghadiri, M. (2016e), "Nonlinear vibration of axially functionally graded non-uniform nanobeams", *Int. J. Eng. Sci.*, **106**, 77-94. https://doi.org/10.1016/j.ijengsci.2016.05.009.

Shafiei, N., Mirjavadi, S.S., Afshari, B.M., Rabby, S. and Hamouda, A.M.S. (2017c), "Nonlinear thermal buckling of axially functionally graded micro and nanobeams", *Compos. Struct.*, **168**, 428-439. https://doi.org/10.1016/j.compstruct.2017.02.048.

Shafiei, N., Mirjavadi, S.S., MohaselAfshari, B., Rabby, S. and Kazemi, M. (2017d), "Vibration of two-dimensional imperfect functionally graded (2D-FG) porous nano-/micro-beams", *Comput. Method. Appl. Mech. Eng.*, **322**, 615-632. https://doi.org/10.1016/j.cma.2017.05.007.

Shafiei, N., Mousavi, A. and Ghadiri, M. (2016f), "On size-dependent nonlinear vibration of porous and imperfect functionally graded tapered microbeams", *Int. J. Eng. Sci.*, **106**, 42-56. https://doi.org/10.1016/j.ijengsci.2016.05.007.

Shafiei, N., Mousavi, A. and Ghadiri, M. (2016g), "Vibration behavior of a rotating non-uniform FG microbeam based on the modified couple stress theory and GDQEM", *Compos. Struct.*, **149**, 157-169. https://doi.org/10.1016/j.compstruct.2016.04.024.

Shafiei, N. and She, G.-L. (2018), "On vibration of functionally graded nano-tubes in the thermal environment", *Int. J. Eng. Sci.*, **133**, 84-98. https://doi.org/10.1016/j.ijengsci.2018.08.004.

Shao, Y., Zhao, Y., Gao, J. and Habibi, M. (2021), "Energy absorption of the strengthened viscoelastic multi-curved composite panel under friction force", *Archiv. Civil Mech. Eng.*, **21**(4), 1-29. https://doi.org/10.1007/s43452-021-00279-3.

Shariati, A., Mohammad-Sedighi, H., Żur, K.K., Habibi, M. and Safa, M. (2020), "Stability and dynamics of viscoelastic moving rayleigh beams with an asymmetrical distribution of material parameters", *Symmetry*, **12**(4), 586. https://doi.org/10.3390/sym12040586.

Shea, C.M. (2005), "Future management research directions in nanotechnology: A case study", *J. Eng. Technol. Management*, **22**(3), 185-200. https://doi.org/10.1016/j.jengtecman.2005.06.002.

Shivanian, E., Ghadiri, M. and Shafiei, N. (2017), "Influence of size effect on flapwise vibration behavior of rotary microbeam and its analysis through spectral meshless radial point interpolation", *Appl. Phys. A.*, **123**(5), 329. https://doi.org/10.1007/s00339-017-0955-9.

Si, Z., Yang, M., Yu, Y. and Ding, T. (2021), "Photovoltaic power forecast based on satellite images considering effects of solar position", *Appl. Energ.*, **302**, 117514. https://doi.org/10.1016/j.apenergy.2021.117514.

Singh, N.A. (2016), *Nanotechnology Definitions, Research, Industry and Property Rights*, Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-39303-2_2.

Singh, N.A. (2017), "Nanotechnology innovations, industrial applications and patents", *Environ. Chemistry Lett.*, **15**(2), 185-191. https://doi.org/10.1007/s10311-017-0612-8.

Song, Z.Q. and Cai, Y.T. (2013), "Application of Nano-Materials in Sports Engineering", *Adv. Mater. Res.*, **602-604**, 281-284. https://doi.org/10.4028/www.scientific.net/AMR.602-604.281.

Su, Q.F. (2014), "Analysis of new materials in competitive sports", *Appl. Mech. Mater.*, **539**, 925-927. https://doi.org/10.4028/www.scientific.net/AMM.539.925.

Wang, P., Gao, Z., Pan, F., Moradi, Z., Mahmoudi, T. and Khadimallah, M.A. (2022), "A couple of GDQM and iteration techniques for the linear and nonlinear buckling of bi-directional functionally graded nanotubes based on the nonlocal strain gradient theory and high-order beam theory", *Eng. Anal. Bound. Elem.*, **143**, 124-136. https://doi.org/10.1016/j.enganabound.2022.06.007.

Wang, P. and Wang, J.Y. (2014), "Development and application of nanotechnology in sports", *Adv. Mater. Res.*, **918**, 54-58. https://doi.org/10.4028/www.scientific.net/AMR.918.54.

Wang, Z., Yu, S., Xiao, Z. and Habibi, M. (2020), "Frequency and buckling responses of a high-speed rotating fiber metal laminated cantilevered microdisk", *Mech. Adv. Mater. Struct.*, 1-14. https://doi.org/10.1080/15376494.2020.1824284.

Wei, D., Pu, N., Li, S.Y., Wang, Y.G. and Tao, Y. (2023), "Application of iontophoresis in ophthalmic practice: an innovative strategy to deliver drugs into the eye", *Drug Delivery*, **30**(1), 2165736. https://doi.org/10.1080/10717544.2023.2165736.

Wu, J. and Habibi, M. (2021), "Dynamic simulation of the ultra-fast-rotating sandwich cantilever disk via finite element and semi-numerical methods", *Eng. with Comput.*, 1-17. https://doi.org/10.1007/s00366-021-01396-6.

Xu, W., Pan, G., Moradi, Z. and Shafiei, N. (2021), "Nonlinear forced vibration analysis of functionally graded non-uniform cylindrical microbeams applying the semi-analytical solution", *Compos. Struct.*, 114395. https://doi.org/10.1016/j.compstruct.2021.114395.

Yano, K., Usuki, A. and Okada, A. (1997), "Synthesis and properties of polyimide-clay hybrid films", *J. Polymer Sci. Part A: Polymer Chemistry*, **35**(11), 2289-2294. https://doi.org/10.1002/(SICI)10990518(199708)35:11<2289::AID-POLA20>3.0.CO;2-9.

Youtie, J., Iacopetta, M. and Graham, S. (2008), "Assessing the nature of nanotechnology: can we uncover an emerging general purpose technology?", *J. Technol. Transfer.*, **33**(3), 315-329. https://doi.org/10.1007/s10961-007-9030-6.

Zare, R., Najaafi, N., Habibi, M., Ebrahimi, F. and Safarpour, H. (2020), "Influence of imperfection on the smart control frequency characteristics of a cylindrical sensor-actuator GPLRC cylindrical shell using a proportional-derivative smart controller", *Smart Struct. Syst.*, **26**(4), 469-480. https://doi.org/10.12989/sss.2020.26.4.469.

Zhang, H., Zou, Q., Ju, Y., Song, C. and Chen, D. (2022), "Distance-based support vector machine to predict DNA N6-methyladenine Modification", *Current Bioinform.*, **17**(5), 473-482. https://doi.org/10.2174/1574893617666220404145517.

Zhang, X., Shamsodin, M., Wang, H., NoormohammadiArani, O., Khan, A.M., Habibi, M. and Al-Furjan, M. (2020), "Dynamic information of the time-dependent tobullian biomolecular structure using a high-accuracy size-dependent theory", *J. Biomolecular Struct. Dynam.*, 1-16. https://doi.org/10.1080/07391102.2020.1760939.

Zhang, Y., Wang, Z., Tazeddinova, D., Ebrahimi, F., Habibi, M. and Safarpour, H. (2021), "Enhancing active vibration control performances in a smart rotary sandwich thick nanostructure conveying viscous fluid flow by a PD controller", *Waves in Random Complex Media*, 1-24. https://doi.org/10.1080/17455030.2021.1948627.

Zhao, H.E. and Shen, F. (2012), "The applied research of nanophase materials in sports engineering", *Adv. Mater. Res.*, **496**, 126-129. https://doi.org/10.4028/www.scientific.net/AMR.496.126.

Zhou, C., Zhao, Y., Zhang, J., Fang, Y. and Habibi, M. (2020), "Vibrational characteristics of multi-phase nanocomposite reinforced circular/annular system", *Adv. Nano Res.*, **9**(4), 295-307. https://doi.org/10.12989/anr.2020.9.4.295.

Zhu, Z.X. (2012), "Research on nano materials tennis rackets", *Adv. Mater. Res.*, **507**, 75-78. https://doi.org/10.4028/www.scientific.net/AMR.507.75.

CC