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Research on safety assessment and application effect of nanomedical products in physical education

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Abstract. This study investigates the application of nano-composite materials in physical education, specifically focusing on improving the performance of sports hall flooring. The research centers on carbon nanotube reinforced polyvinyl chloride (PVC) composites, which offer enhanced mechanical properties and durability. The incorporation of carbon nanotubes as reinforcements in the PVC matrix provides notable benefits, including increased strength, improved thermal stability, electrical conductivity, and resistance to fatigue. The key parameters examined in this study are the weight percentage of carbon nanotubes and the temperature during the fabrication process. Through careful analysis, it is found that higher weight percentages of carbon nanotubes contribute to a more uniform dispersion within the PVC matrix, resulting in improved mechanical properties. Additionally, higher fabrication temperatures aid in repairing macroscopic defects, leading to enhanced overall performance. The findings of this study indicate that the utilization of carbon nanotube reinforced PVC composites can significantly enhance the strength and durability of sports hall flooring. By employing these advanced materials, the safety and suitability of physical education environments can be greatly improved. Furthermore, the insights gained from this research can contribute to the optimization of composite material design and fabrication techniques, not only in the field of physical education but also in various industries where composite materials find applications.

Keywords: carbon nanotubes; nano-composites; physical education; polyvinyl chloride (PVC) composites; sports hall flooring

1. Introduction

Nanotechnology involves the intersection of many disciplines and derives nanomedical products for diagnosis and treatment. Composites are materials consisting of two components: the background material and the reinforcing material. The background component typically possesses poor mechanical, electrical, and thermal properties (Jagadeesh *et al.* 2022). To address these limitations, reinforcing components are added to enhance the desired properties. Nano-composites, on the other hand, incorporate nanomaterials as reinforcing agents, offering promising properties and finding applications in various fields such as packaging and automobile manufacturing (Mousavi *et al.* 2022b).

In the realm of nano-composites, an important factor is the high surface-to-volume ratio of the nano-reinforcements, leading to strong interactions between the reinforcing component and the background material (Barbaros *et al.* 2022, Tripathy and Biswas 2022). When a proper interaction occurs between these components, the overall properties of the nanocomposite are strengthened (Zhou *et al.* 2022). Nano-composites exhibit several characteristics influenced by the size of the particles, including a high surface-to-volume ratio, excellent flexibility without compromising strength, scratch resistance, and favorable optical properties such as transparency (Shah *et al.* 2022).

The polymer substrate can uniformly transfer the forces applied to the composite to the reinforcing material by sticking to the mineral materials (Mousavi *et al.* 2022a). Types of nanocomposites include polymer-based nanocomposites, ceramic-based nanocomposites, and metal-based nanocomposites (Atmane Hassen *et al.* 2015, Attia *et al.* 2015, Bennai *et al.* 2015, Chaht Fouzia *et al.* 2015, Kar Vishesh and Panda Subrata 2015, Houari Mohammed Sid *et al.* 2016, Bellifa *et al.* 2017, Avcar 2019, Zarga *et al.* 2019). Among nanocomposites, the focus is on polymer-based nanocomposites (Mishra *et al.* 2022). The excellent mechanical, chemical, and physical properties of polymer nanocomposites are one of the reasons for their expansion. (Iqbal Khan *et al.* 2022). The characteristics of polymer nanocomposites are high strength, low weight, high thermal stability, high electrical conductivity, and high chemical resistance (Ogbonna *et al.* 2022). The following are the advantages of using polymer nanocomposites:

The final piece has a lower weight than average composites, higher mechanical strength at lower load, high gas and vapor penetration resistance, a better surface, more effortless process ability, and higher heat tolerance (Alsultan Abdulmajeed 2021, Dai *et al.* 2021, Alimoradlu and Zamani 2022, Behdinan and Moradi-Dastjerdi 2022, Thakur *et al.* 2022, Zhao *et al.* 2022a). A point that is important in the production methods of polymer nano-

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composites and distinguishes them from each other is the proper distribution of the filler material. By modifying the surface, this distribution can be done uniformly so that the agglomeration of the nanometer components of the filler material is prevented and the proper distribution of the reinforcing phase is provided (Mohammadi *et al*. 2020, Wang *et al*. 2020, 2023, Ugurlu and Ozturk 2021, Dehghanbanadaki *et al*. 2022). The critical point in all these processes is modifying the polymer and nanoparticle interface. The use of surface processes will result in the uniform distribution of the polymerized substrate's reinforcing phase, increasing the nanocomposite's modulus and strength (Chen *et al*. 2021, Esparham *et al*. 2021, Raj *et al*. 2021, Shahram Ghaedi Faramoushjan Hossein Jalalifar 2021, Cai *et al*. 2021, Maheswaran *et al*. 2022, Shariq *et al*. 2022).

The development of polymer-based nanocomposites and increasing study in this field is the finding of carbon nanotubes in 1991 (Zheng *et al*. 2004). Carbon nanotubes' strength and electrical properties significantly differ from graphite nanolayers and other filler materials (Zhang *et al*. 2019). Carbon nanotubes have created many activities in science and engineering due to their unique chemical and physical properties (Han *et al*. 2019). These combined properties make them suitable for filling materials in composites. Researchers envision the advantages of high conductivity and aspect ratio for producing conductive plastics with very low leakage thresholds (Su *et al*. 2020). Nanotubes can have diameters of 1 to 100 nm and lengths up to the millimeter scale (El-Sheikh *et al*. 2019). There are two original kinds of nanotubes: single-walled nanotubes wrapped with a layer of graphite to form tubes with diameters between 1-10 nm. Multi-walled nanotubes that include an array of concentric tubes. Multi-walled nanotubes can have diameters of 2 to 100 nm (Norizan *et al*. 2020).

In a study by Ahmad *et al*. (2022), the outcomes of carbon nanotube addition and radiation modification on the mechanical demeanor and thermal resilience of epoxidized natural rubber/polyvinyl chloride/carbon nanotube nano-composites were studied. The storage modulus and glass transition temperature improved by increasing nanotube content increased.

In a sports club, to teach physical education and achieve the desired goals, in addition to an expert and experienced trainer and talented and productive students, suitable facilities are needed in the desired field (Cojocaru *et al*. 2022). It is noteworthy that the efficiency of any organization decreases when material facilities and human resources are in the way (Deussom *et al*. 2022). One of the most important first steps in constructing sports facilities is selecting a suitable location. These facilities can be built in any area. They will have usability. Members of society are looking for a standard and excellent sports space. It is a part of the duties of managers and officials of physical education in society to prepare and predict the facilities, equipment, and sports equipment needed now and in the future (Misener *et al*. 2022). Considering the role of physical education in society, sports spaces in different cities can be the basis for social growth and achieving the goals of physical education. Sports hall flooring is essential nowadays (Li *et al*. 2022, Xiong *et al*. 2022, Zhao *et al*. 2022b, Su *et al*. 2023). Therefore, due to its high flexibility, this flooring ensures the level of safety of athletes while exercising in clubs and gyms and prevents irreparable injuries (King *et al*. 2002). In addition to gyms, sports floors are used in public places such as kindergartens, parks, and amusement parks. Of course, the sports flooring type differs depending on the location (Gillespie 2008). However, the noteworthy point here is that sports floors, in addition to providing high safety, should create a more comfortable environment. and provide an easier time for the athlete during sports exercises, which is considered one of the essential features of sports flooring (Olsen *et al*. 2003). The material flooring must be produced from first-grade rubber raw material. The flexibility and longevity of flooring are essential points when buying flooring. Easy installation, washing ability, and resistance to water and humidity are other characteristics of high-quality sports flooring (Harifi and Montazer 2015).

When purchasing sports flooring, safety is a prioritized factor, as it plays a critical role in preventing potential and irreparable injuries during sports activities (Ding and She 2021, Cuong Bui 2022, Soltanieh *et al*. 2022, Wu *et al*. 2022). However, despite the advancements in polymer-based nanocomposites and the potential of carbon nanotubes as reinforcing agents, there are still challenges to overcome. One of the main shortcomings lies in achieving a uniform distribution of the nanotubes within the polymer matrix, which is crucial for optimizing the mechanical properties of the nanocomposites (Cheng *et al*. 2023, Guo *et al*. 2023, Huang *et al*. 2023, Tang *et al*. 2023, Wu *et al*. 2023, Zhao *et al*. 2023). Additionally, the proper interface between the polymer and nanotubes needs to be established to ensure effective load transfer and interaction between the components. Bridging this gap between the potential benefits and the current limitations is essential to harness the full potential of nano-composite materials in the field of physical education. By addressing these challenges and exploring innovative fabrication techniques, it is possible to unlock new possibilities and create safer, more durable, and high-performance sports hall flooring.

2. Materials and equipment

The materials and equipment mentioned in Table 1 have been used to synthesize nanocomposite to strengthen the flooring of the sports hall.

3. Methods

3.1 Preparation instructions for carbon nanotubes

The multi-walled carbon nanotubes (MWCNTs) were warmed in an oven at 300 °C for 50 minutes to separate the amorphous carbon from them. Then the reflux process was performed for 3 hours at 100 °C with concentrated nitric acid. Carbon oxide nanotubes and their closed ends are extended to increase the specific surface area of nanotubes. Excess nitric acid was removed from the surface of the

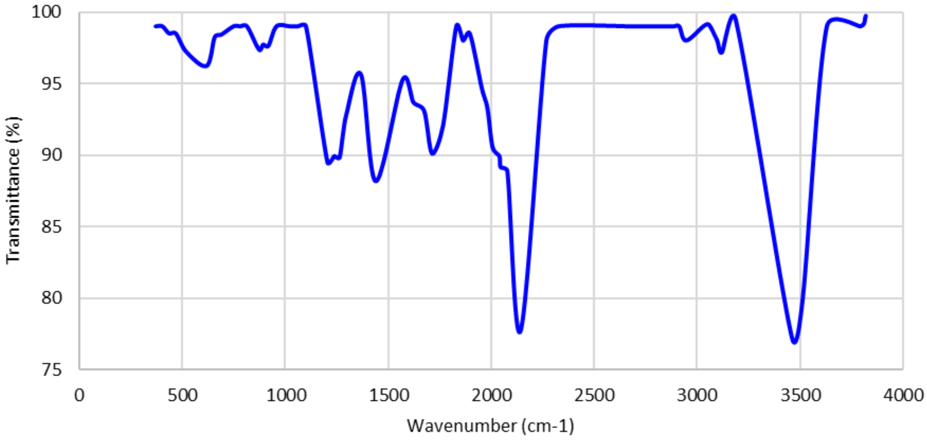

Fig. 1 The infrared spectrum of carbon nanotubes

Table 1 Materials and equipment

Materials	Equipment
Carbon nanotubes	Scanning electron microscope (SEM)
Nitric acid	Oven
Distilled water	FT -IR spectroscopy
Tetrahydrofuran (THF)	Thermal gravimetric analysis (TGA)

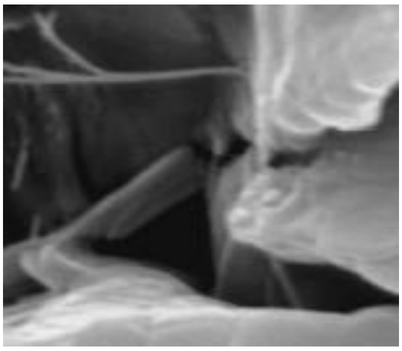

Fig. 2 The covalent bond between PVC polymer and carbon nanotube in the composite

nanotubes with sufficient distilled water, and the nanotubes were placed in an oven at 80°C for 3 hours and stored in closed containers. FT-IR spectroscopy of oxidized carbon nanotubes was analyzed.

3.2 Fabrication of PVC nanocomposite - carbon nanotube

Tetrahydrofuran solution has been operated to disperse the synthesized nanotubes. The polymer chosen to be connected with the plastic matrix of the flooring is PVC, with a melting point of 180°C. PVC seeds are poured into the mold, and when the mold temperature reaches the melting temperature of PVC, the carbon nanotube solution is sprayed into the mold. The material spray temperature is adjusted so that at the end of the spray process, the bottom layer of the polymer is in the form of a paste. After creating a layer of carbon nanotubes on the polymer, a unique polymer layer is added to the selected floor covering layer, and then pressing is done on the mold. This method is repeated to make a nanocomposite with the expected number of layers. An image of the covalent bond formation between the PVC/multi-walled carbon nanotube nanocomposite is taken. Thermal gravimetric analysis (TGA) was used to confirm the weight percentage of different carbon nanotubes in the PVC matrix. The strength of the produced nanocomposite was checked, and the SEM image was taken from the fracture surface of the samples. Finally, the fatigue strength of nanocomposites was checked.

4. Result

4.1 FT-IR spectroscopy of carbon nanotubes

Fig. 1 shows the FT-IR spectrum of carbon nanotubes. Peaks between 2800-3800 cm-1 of the peaks are characteristic of the expansion vibrations of C-H and O-H bonds. These peaks can be attributed to carboxylic acid and hydroxyl groups. The peaks at 1500 cm-1 indicate the beginning of the formation of carboxylic groups. The peak at 1700 cm-1 corresponds to the stretching vibrations of the C=O class.

4.2 Formation of the covalent bond between carbon nanotube and PVC in composite

In the presence of heat, PVC powder and carbon nanotubes can form strong covalent bonds, and charge transfer from carbon nanotubes to PVC increases (Fig. 2) as the load transfer surface becomes wider. Finally, the compressive strength of the nanocomposite increases. Another reason can be seen in the filling property of PVC under heat. Due to the development of PVC powder in the sample due to temperature, small cracks are filled by PVC and carbon nanotube, preventing crack growth. This quickly increases the compressive strength of the sample containing the synthesized composite. Therefore, combining PVC and carbon nanotubes positively affects the sample’s mechanical properties. The temperature applied to this nanocomposite is 150 °C.

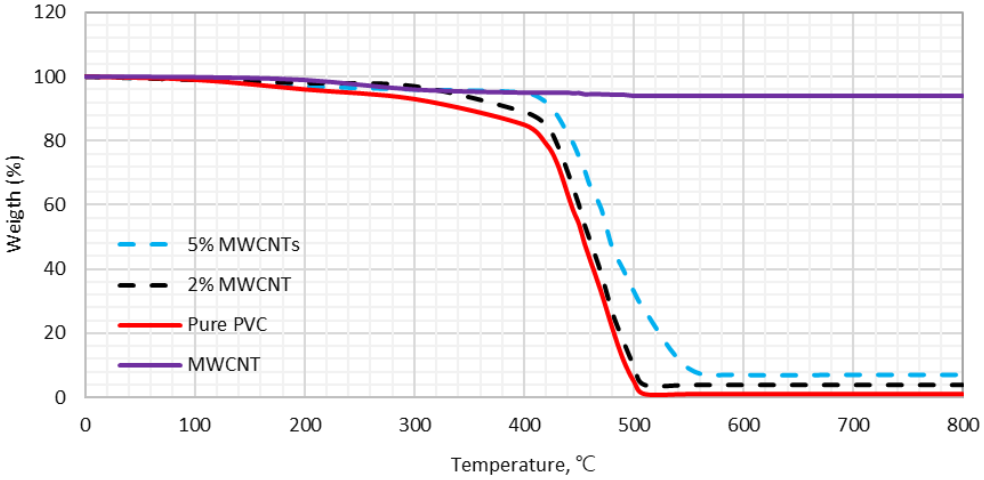

Fig. 3 Thermal analysis for PVC/carbon nanotube nanocomposite

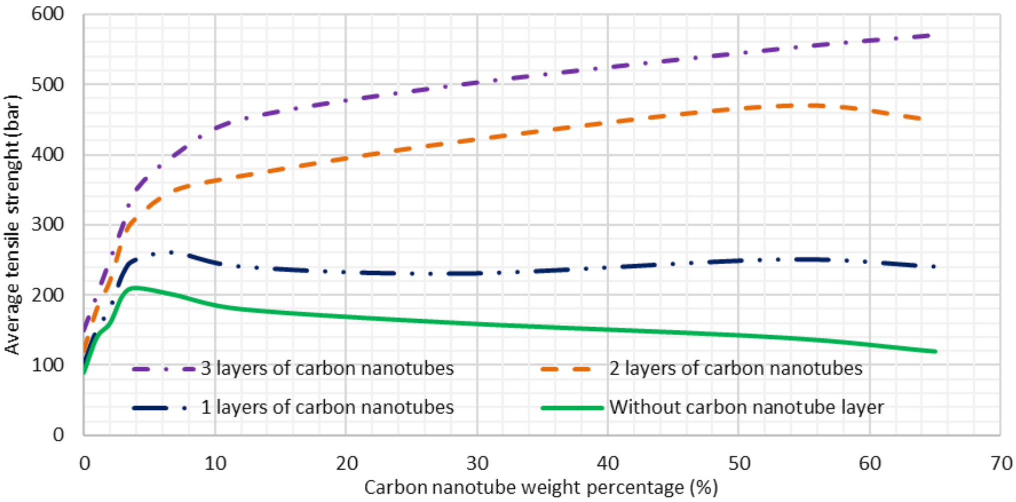

Fig. 4 The result of the number of layers and weight percentage of carbon nanotubes on the resilience of nanocomposite

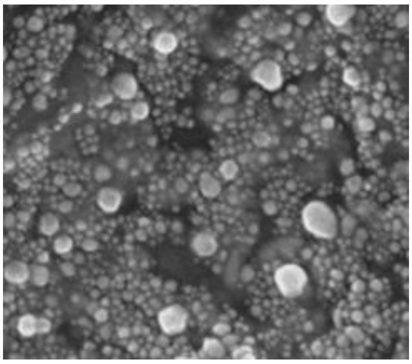

Fig. 5 SEM image of a fracture surface of PVC nano-composite/multi-walled carbon nanotube

4.3 Thermal gravimetric analysis

The TGA method is the simplest thermal analysis method, based on measuring the weight of the sample during heating. This method provides valuable information when materials decompose during heating or react with the surrounding gaseous environment. The horizontal and vertical axes show the temperature in degrees Celsius and the weight change percentage, respectively. The starting and ending temperatures of each thermal event in the TGA curves depend on the conditions of the experiment. The most important influencing factors are the heating speed, furnace environment, sample characteristics, and shape and material of the sample container. Pure PVC starts to degrade in a nanocomposites, the charge transition from matrix to nitrogen atmosphere at a temperature of 220 °C and

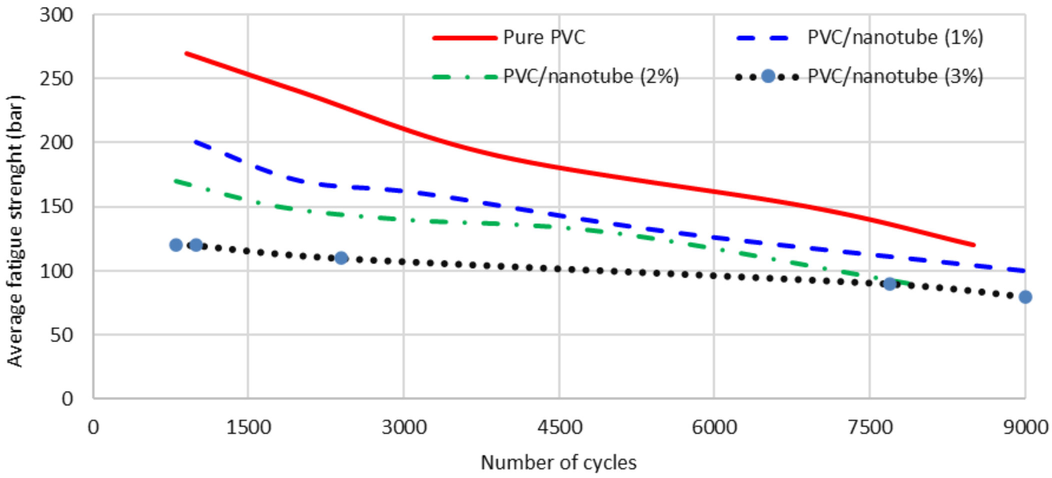

Fig. 6 Effect of carbon nanotube percentage added to PVC on tiredness strength of nanocomposite

completely degrade at a temperature of 510 °C. The results for weight percentages 2 and 5 are entirely in their desired points. For the PVC/carbon nanotube nanocomposite samples, the weight percentage of the carbon nanotube is determined after the temperature of 510°C and when the PVC is completely dissolved. The weight of the carbon nanotube stays reasonably stable at 515 °C. The results of this analysis are shown in Fig. 3.

4.4 Nanocomposite strength

Due to the smooth placement of nanotubes in layered nanotubes is better. The results show that in exact and identical weight ratios, the fracture strength of the nanocomposite increases with the increase of carbon nanotube layers. In all fabricated samples, the ultimate tensile strength increases with the weight percentage of carbon nanotubes. However, in the non-layered nanocomposite, the decreased onset occurred after the ultimate tensile strength increased. This reduction in mechanical properties happens with the growth in the number of layers in a higher weight percentage of carbon nanotubes. The more the number of layers with the weight percentage of carbon nanotubes remains constant, the percentage of defects decreases, and the distribution of nanotubes improves. As a result, the mechanical properties are improved (Fig. 4). If the goal is only to increase the final strength and bring it to the maximum value, the highest weight percentage of carbon nanotubes, 67%, is suitable, But the optimal mode for the weight percentage of Carbon nanotubes is 8%, Because the optimal case, the consumption of carbon nanotube should be reasonable compared to the improvement of mechanical properties.

4.5 SEM image of a nanocomposite fracture surface

Fig. 5 shows the SEM image of the broken surface of the nanocomposite. Proper and efficient distribution of carbon nanotubes in the PVC matrix can be seen. Also, the fracture surface shows that the carbon nanotubes are aligned in the stretching tendency of the nanocomposite, which increases the final strength of the nanocomposite.

4.6 Tiredness strength of nanocomposites

The microstructural mechanisms of damage aggregation include carbon nanotube fracture and matrix cracking. Layering sometimes occurs independently and sometimes mutually. The superiority of each is strongly influenced by the two factors of material variables and test conditions. The distribution of particles and the strength of the interface are essential factors in determining the fatigue strength of composites. The slope of the graphs increased with the increase of carbon nanotubes. This shows that for nanocomposites with a higher weight percentage of nanotubes, the tiredness strength of the nanocomposite decreases with the increasing number of cycles. By increasing the weight percentage of carbon nanotubes in the PVC matrix, the probability of nanotubes accumulating in one pinpoint increase and thus shows more significant weaknesses. These defects reach the failure stage faster under dynamic loads such as fatigue testing. Fractures are initially caused by layering, which is caused by the interaction of matrix and polymer. As a result of layering, stress is concentrated at the fracture site, accelerating the fracture of nanotubes and matrix and leading to complete failure. Putting carbon nanotubes in the polymer matrix eliminates the creation of micro-cracks during cyclic loads, thus preventing the expansion of these cracks and reducing the impact of delamination. The graph of the influence of the percentage of carbon nanotubes added to PVC on the tiredness strength of the nanocomposite is shown in Fig. 6.

5. Discussion

One of the critical factors in enhancing the mechanical properties of nanocomposites strengthened with carbon nanotubes is the appropriate distribution of nanotubes in the matrix and their orientation in the loading direction. Improving carbon nanotubes' weight percentage improves the nanotubes' accumulation at one point, reducing the nanocomposite's mechanical properties. One of the most powerful methods to control this issue in standard procedures is employing functionalized nanotubes. The strength of a material is equal to the maximum stress that the material can withstand beneath uniform tension, which is sometimes equal to the yield stress and sometimes equal to the breaking stress of that material. In the case of polymer composites that include micro- or nano-sized mineral particles, strength is affected by stress transfer between the matrix and fillers, which is influenced by factors such as particle size, particle amount, and particle compatibility with the polymer matrix.

All over the world, sports are an inseparable part of people. People turn to all kinds of sports to escape from everyday life and store the feeling of peace and energy. Alternatively, even some choose sports as their first job and earn money. Today’s people are aware of the impact of sports on the body and know that their health depends on this process. They should be aware of the effect of sports equipment. The first step to having a great sports experience is to have vital and good- quality sports equipment. If sports equipment is solid and durable, it will also have a long lifespan in addition to increasing sports performance. The more durable and robust the sports equipment, especially the equipment such as the floors used in gyms, the better feedback is received from exercising and physical education training takes place in a safe and suitable environment. Sports halls, as one of the most attractive places, always welcome a large number of professional athletes as well as amateurs who spend considerable time in it every day. The need for mobility, speed, and strength in sports causes athletes to be constantly exposed to various injuries. A significant percentage of injuries occur due to the inappropriate covering of the floor of sports environments and cause severe injuries to the athletes’ bodies. The most important feature of sports flooring is elasticity. Also, due to people’s high traffic and mobility, these floors must have high wear resistance. In addition, it should be kept in mind that a large number of people and their mobility in sports spaces makes the possibility of disease transmission between people due to contact with the flooring high. In addition, they should have low slipperiness to prevent the athletes from slipping and high colorability so that different colors can be used to insert sports signs. They should have enough strength when heavy equipment falls. Using nano additives is considerably helpful in enhancing many products’ final developments. Nanocomposites can improve the mechanical strength of many products and prevent oxygen, moisture, ultraviolet rays, and volatile substances from entering them. The technology of polymer nanocomposites has led to many innovations with different applications in different sectors. Improving the properties and higher quality of products increases their lifespan.

6. Conclusions

The investigation into the application of carbon nanotube reinforced polymer nanocomposites in the context of sports hall flooring has provided significant findings. The mechanical properties of the resulting nanocomposites were found to be influenced primarily by two key parameters: the weight percentage of carbon nanotubes and the temperature of the mold bed during fabrication.

The addition of carbon nanotubes to the polymer matrix introduced certain defects, while increasing the temperature of the mold bed facilitated the repair of some macroscopic defects in the nanocomposite. Notably, a higher weight percentage of nanotubes in the polymer resulted in fewer defects, particularly when coupled with an increased number of nanotube layers. This led to an improved distribution of nanotubes, ultimately enhancing the mechanical properties of the nanocomposites.

Furthermore, the tensile testing revealed that carbon nanotubes exhibited quick orientation perpendicular to the fractured part, owing to the layered nature of the nanocomposites. Composite materials, being non-homogeneous and non-isotropic, exhibit a more complex behavior compared to homogeneous and isotropic materials like metals. This complexity arises from various types of damages, their interactions, and differing growth rates within the composite materials. Typically, the initiation of damage in composite materials occurs within the initial cycles, progressively growing and ultimately resulting in failure.

It was observed that the fatigue strength of the nanocomposite decreased as the weight percentage of carbon nanotubes increased, particularly with an increased number of cycles. However, the incorporation of carbon nanotubes within the polymer matrix effectively inhibited micro-crack formation during cyclic loads, preventing the development of such cracks and reducing delamination. Notably, the reduction in fatigue strength was mitigated with an increasing number of carbon nanotube layers, attributed to the decreased presence of defects in the layered nanocomposite structure.

Hence, by employing this methodology and improving the number of carbon nanotube layers within the PVC matrix, it is possible to enhance the fatigue strength of the PVC/carbon nanotube nanocomposite. The application of such advanced composites in sports hall flooring can significantly contribute to the overall strength and durability of these surfaces.

Future research endeavors should continue to explore and optimize the integration of carbon nanotube reinforced polymer nanocomposites, taking into account factors such as weight percentage, distribution, and layering. By further advancing the fatigue strength and overall performance of these materials, the widespread adoption of such nanocomposites in sports hall flooring and related applications can be realized, providing safer and more robust environments for physical education activities.

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