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Enhancing sports equipment performance: Development of polyvinyl chloride-based nanocomposites with plantain wood powder and nano clay

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Abstract. Nanotechnology enables exact manipulation at the nanoscale, resulting in game-changing solutions across numerous sectors. This work investigates the development of a new polyvinyl chloride (PVC)-based nanocomposite using plantain wood powder and nano clay, with a focus on increasing mechanical qualities for use in sports equipment. The use of nano clay significantly improves elastic modulus and bending resistance, providing cost-effective and environmentally friendly alternatives to traditional materials. Furthermore, the material has an excellent resistance to water absorption, ensuring its endurance in a variety of climatic circumstances. The proposed nanocomposite has outstanding qualities for protective equipment, helmets, and sports gear, thereby enhancing player safety and performance. The incorporation of nano clay into PVC composites addresses the limitations of traditional materials, particularly their durability and flexibility issues. The findings highlight the material's potential to transform sports equipment manufacturing by offering lightweight, long-lasting, and environmentally responsible alternatives. Furthermore, the material's biodegradability aligns with global environmental goals. This research highlights nanocomposites' ability to advance material science and enhance the quality of sporting equipment.
Keywords: mechanical properties; nano clay; nanocomposites; plantain wood powder; Polyvinyl Chloride (PVC); sports equipment performance

1. Introduction

Effective management of financial resources has become increasingly evident in our daily lives (Backman 2004). By examining the day-to-day economic activities, we can grasp the significance of managing financial resources (Kaufman 2012). Financial management encompasses various methods that govern the financial cycle of human life and offer insights into the overall economic situation (Goyal *et al.* 2021). In essence, financial resource management employs economic principles to address diverse challenges (Siano *et al.* 2010). While financial management encompasses multiple domains such as the education and production industries, its core focus remains on managing finances in personal life (Kester 1986). Opting for the most suitable financial management software relies on an individual's budget and specific requirements, with the understanding that the priciest and most comprehensive software may not be the ideal choice for everyone (Ozerov *et al.* 2017). One of the key objectives of financial resource management is to maximize the value of a company (Mihajlović *et al.* 2020). The financial manager is associated with owners and people who are capital market participants (Petty and Bowlin 1976). Therefore, they need a good plan for the company's profit and growth (Lakonishok *et al.* 1992). The evolution of financial management over the past century has led to its emergence as a distinct scientific discipline in the early 20th century (Drucker 2007). Prior to this period, financial management was regarded as a component of applied economics, particularly in the 1890s and 1900s (Havik 2015). Notably, in the 1920s, key industries like steel, automobile manufacturing, and chemicals witnessed substantial growth and progress (Kurth 1979). Due to the increase in profit margins and the decrease in the inventory of companies due to the decrease in prices in 1920 and 1921, the issue of financial structures became more critical (Omidi *et al.* 2013, Ghadiri *et al.* 2016, Mousavi *et al.* 2017). Price changes made companies and industries aware of the importance of liquidity control and capital structure (Thomsen and Pedersen 2000, Karadeniz *et al.* 2009, Chen *et al.* 2010). The use of the property system, which is related to the purchase, maintenance, and repair of units and the warehouse in the form of a process, leads to the management and costing of all the organization's properties and the calculation of automatic depreciation related to maintenance and repairs (Ren 2022). Among the features of financial resource management:

They proceed based on analysis, pay attention to economic principles, and use the information provided by

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accounting (Li and Fang 2022, Thuan *et al*. 2022). What makes up organizations and businesses is human power (Bohórquez *et al*. 2023). Nevertheless, it may be thought that due to the introduction of various technologies in modern companies and organizations, human power has become less critical and is no longer as important as in the past (Kandampully *et al*. 2022). Unfortunately, with the mechanization of industries, many managers do not value employees and human resources and have neglected them (Baur and Iles 2023). At the same time, they should learn that the most important thing for any business is human resources, or in a more correct and better way, human resources management (Dai *et al*. 2021b, Huo *et al*. 2021, Chen *et al*. 2022, Guo *et al*. 2024a, He *et al*. 2024, Huang *et al*. 2024, Jin *et al*. 2024, Jining *et al*. 2025). Human resource management is needed in any business where more than two people are active. In general, it does not matter for a small or large business, and human resources are equally the most crucial factor for its success (Alqudah *et al*. 2022). If the human forces are not in their proper place, they will not be effective (da Silva *et al*. 2022). Many times, people with opposite skills have developed an entrepreneurial idea well (Good and Schwepker 2022). Human power is the owner of the main idea of a thoughtful, emotional, introverted, creative, and idealistic personality, and on the other hand, her partner is a pragmatic, logical, extroverted, social, and realistic person. The combination of these two items can implement a good idea (Higgins *et al*. 2013).

One of the lucrative jobs is furniture making. There are so many houses with sofas and armchairs (Gustafsson 1997). This importance and bold presence have been extended outside the homes and offices, and workplaces decorate their space with office furniture (Besch 2005). Like some other jobs, this job has its conditions and principles, and it can be safely said that it is one of the most profitable jobs (Barsky 1981). High employment generation, great diversity in models and designs, and prosperity for some industries, such as textile, multiply the importance of this industry (Wilkie and Young 1972). Wood is one of the essential natural elements for beautifying decorative products. Among the other factors that are highly regarded in the wood industry are the strength, thickness, and quality of wood, due to these two characteristics, the essential element of beauty as well as strength and quality, makes wood the central pillar of furniture making (Sambe *et al*. 2022). In the furniture industry, workshops and furniture factories are always looking for quality wood in terms of durability, strength, beauty, and affordability (Adedeji *et al*. 2022). In order to sell their products as much as possible, furniture workshops produce sofas with different qualities so that they can attract the opinion of customers to buy their products in any way (Xin 2022).

Financial management is a critical and integral component for all companies, economic enterprises, and even governments to plan, organize, direct, and control all financial activities (Alsultan Abdulmajeed 2021, Dai *et al*. 2021a, Alimoradlu and Zamani 2022, Behdinan and Moradi-Dastjerdi 2022, Thakur *et al*. 2022, Zhao *et al*. 2022). This concept has existed among people since ancient times, but over time, its importance has been felt more than before (Bai *et al*. 2022, Lu *et al*. 2023, Yu *et al*. 2023, Jin *et al*. 2024, Wang *et al*. 2024g). Also, with the emergence of new technologies, more progress is expected in this field (Bustani *et al*. 2022).

Traditional materials in sports equipment manufacture often fail to strike a balance between durability, flexibility, lightweight qualities, and environmental sustainability (Li *et al*. 2022, 2024a, b, 2025, Liang *et al*. 2024, Liu *et al*. 2024b, 2025a, Ma *et al*. 2024). Existing composites usually have drawbacks such as poor water resistance, decreasing mechanical strength under changing environmental conditions, and high manufacturing costs, which prevent broad use. This study closes the gap by presenting a unique PVC-based nanocomposite reinforced with plantain wood powder and nano clay. Plantain wood powder not only improves the mechanical qualities of the composite, but it also adds an environmentally favorable dimension owing to its biodegradability (Kou *et al*. 2024a, Liu *et al*. 2024a, Zhu *et al*. 2024). Meanwhile, nano clay dramatically increases elastic modulus and bending resistance, solving the fundamental challenges of durability and flexibility that afflict traditional materials (Wang *et al*. 2024e, Wang *et al*. 2024h, Zhang *et al*. 2024b). This study is unique in that it combines renewable resources with modern nanotechnology to create a material that is both cost-effective and ecologically friendly. By combining these elements, the research lays the way for substantial advances in sports equipment design, resulting in lightweight, durable, and sustainable solutions that fulfill global environmental objectives. Thus, this discovery not only fills a huge gap in material science, but it also establishes a new benchmark for the production of high-performance sports equipment, leading to improved player safety and performance.

2. Methods

In this study, Platanus tree powder was employed as the dispersed phase in the nanocomposite material. The continuous phase consisted of both pure and recycled polyvinyl chloride, along with additives such as maleic anhydride enriched with polypropylene (MAPP), which served as an adhesive between the dispersed phase and the polymer (Wang *et al*. 2024b, c, d, g, Xiao *et al*. 2024, Xue *et al*. 2024, Yin *et al*. 2024, Xia *et al*. 2025). Additionally, calcium stearate and zinc stearate were used as stabilizers, while nanoclay served as a thermal modifier. Table 1 presents a comprehensive list of the materials and equipment utilized for the production of this nanocomposite, aimed at enhancing the quality of wooden furniture for marketing purposes, while focusing on customer expected value and satisfaction.

Fig. 1 depicts the development and use of a novel PVC-based nanocomposite material using plantain wood powder and nano clay to increase mechanical properties for use in sporting equipment. The schematic is divided into three sections: material preparation, property enhancement, and final application. The first section shows how the fundamental materials—PVC, plantain wood powder, and nano clay—are mixed and processed to form the nano-

Fig. 1 Schematic representation of polyvinyl chloride (PVC)-based nanocomposite incorporating plantain wood powder and nano clay for enhanced sports equipment performance

composite. The second section focuses on the significant advantages enabled by this combination, such as increased elastic modulus, bending resistance, and reduced water absorption, all of which add to the material's durability and environmental sustainability (Guo *et al*. 2025, He *et al*. 2025). Finally, the last section illustrates the nanocomposite's practical applications in various sports equipment, including as helmets, protective pads, and other gear, emphasizing its capacity to improve player safety and performance. This image demonstrates how mixing nano clay and plantain wood powder into PVC may provide new, lightweight, and ecologically friendly materials that surpass the limitations of traditional sports equipment materials (Su *et al*. 2021, Huang *et al*. 2022, Xu *et al*. 2023).

2.1 Factors examined

Considering the effect of various factors on the characteristics of this type of nanocomposite, the purpose of this work is to use pure and recycled polyvinyl chloride and the effect of nanoclay in producing this nanocomposite in order to send it to workshops and furniture companies

Table 1 Materials and equipment

Material names	Equipment names
Nanoclay	Oven
Zinc stearate	Injection device
Polypropylene	Extruder machine
Calcium stearate	Granulator machine
Platanus tree powder	
Polyvinyl chloride (PVC)	
Maleic anhydride enriched	

Table 2 The weight percentage of nanocomposite ingredients

Materials	Control sample 1	Sample 2	Sample 3	Sample 4
Wood powder	0	20	30	40
PVC	100	62	52	42
MAPP	0	5	5	5
Calcium stearate,	0	5	5	5
Zinc stearate	0	8	8	8

(Jermsittiparsert *et al*. 2022, Huang *et al*. 2024, Song *et al*. 2024, Xiao *et al*. 2024, Zhiqiang *et al*. 2024, Zisong and Habibi 2024).

Which can improve economic and financial conditions for the sale of this furniture and customer satisfaction. In this research, two steps are considered for making nanocomposite. In the first stage, the amount of wood powder in three levels is 20, 30, and 40%, and the type of polyvinyl chloride in the three levels is pure, recycled, and a mixture of their pure and recycled form in a weight ratio of 50:50%. The amount of nanoclay based on the weight of the samples was used in three levels 1, 3, and 6%. Fixed factors include wood powder with a specific weight of 0.6 grams per cubic centimeter. Maleic anhydride test was used to compare the averages of each factor and their mutual effect (Qi *et al*. 2024, Wang *et al*. 2022, Jia *et al*. 2023, Zhang *et al*. 2023a, b, c, Wang *et al*. 2024a, Yan *et al*. 2024). Step 1 of making enriched with polypropylene was prepared at 5% by weight, and calcium stearate 5% and zinc stearate were used at 8% by weight. This study was conducted in a completely randomized design with 9 treatments combining two factors. The independent and mutual effect of each factor was analyzed in the form of a 3×3 factorial test using the analysis of the variance table at the 1% level, and Duncan's nanocomposite.

In order to find the best weight percentage of wood powder with a polymer that does not harm the properties of the resulting composite and check the behavior of PVC different from wood, the weight percentages of Platanus wood powder and polymer were used as described in Table 2.

2.2 Construction processes

To prepare the initial mixture of wood and PVC, according to the necessary percentages of materials in each composition mentioned in Table 2, each is prepared and poured into a container and stirred until a uniform mixture is prepared. Thermal stabilizers such as calcium and zinc stearate were added to the mixture to prevent the loss of sample properties during the process. After preparing the mixture, it was poured into the extruder, and the mixing operation was performed (Kou *et al*. 2024b, Qian *et al*. 2024, Liu *et al*. 2025b). Then the product entered the cooling chamber containing water in the form of a thin string and was turned into granules in the granulator machine, and the resulting granules were placed in an oven with a temperature of 70 degrees Celsius for 24 hours to dry. The granule dried by the injection machine in process conditions of 120, 130, and 140 degrees Celsius with a pressure of 80 bar and a speed of 60 rpm were converted into the tested samples for conducting physical and mechanical tests.

3. Examining the physical and mechanical properties of the samples

3.1 Bending test

The tester determined the bending properties of the samples. In this part, the loading speed was set the same for all samples, and they were loaded with one speed (5mm/min), and the distance of the support bit was considered 50 mm. After drawing the diagram and determining the range of elastic behavior of the samples under load, its modulus of elasticity (MOE) is calculated according to the following equation (Babiak *et al*. 2018):

$$MOE = \frac{1}{4}\frac{f \times l^3}{b \times d^3 \times D} \quad (1)$$

In which ‘f’ is Force at the elastic limit, ‘l’ is the distance between two supports, ‘b’ is sample width, ‘d’ is sample thickness, and ‘D’ is the amount of bending at the elastic limit (Han *et al*. 2024, Wang *et al*. 2024f, Zhao *et al*. 2024).

3.2 Water absorption

To check the amount of water absorption, the samples were placed in water after weighing, and during 72 hours ($WA_{(72)}$) of immersion in water, their water content is calculated as follows (Saba *et al*. 2019):

$$\frac{WA_{(72)}}{100} = \frac{w - w_0}{w_0} \quad (2)$$

where, ‘WA’ is water absorption, ‘w’ is the mass of the sample after 72 hours of immersion in water, and ‘w_0’ is the initial mass of the sample (Zhang *et al*. 2017, 2022, 2024a).

4. Results and discussion

4.1 Results of bending strength

The effect of PVC type on bending strength was significant at a 1% level. Means were compared using Duncan’s test, shown in table 4. The highest bending strength is related to the composite made with mixed PVC because the use of mixed PVC containing impurities from the recycled part is more rigid than pure PVC, but because pure PVC is soft, it has meager resistance (Guo *et al*. 2024b, Zhang *et al*. 2024c).

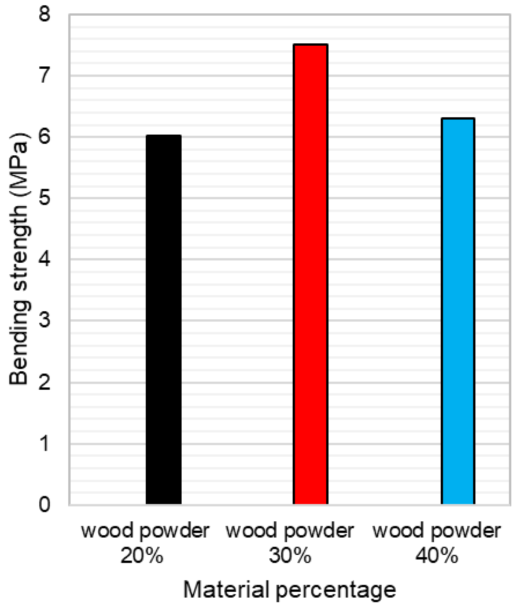

Fig. 2 The effect of wood amount on bending strength

Table 3 The effect of PVC type on composite bending strength and its grouping by Duncan’s method

Duncan’s grouping at the 1% level	Bending strength (1)	PVC
A	5.62	Pure
A	7.45	Recycled
B	8.82	Mixed

4.2 Effect of amount of plantain wood powder on bending strength

According to the Fig. 2 and the results of the analysis of variance, the highest bending power is related to the composite made with 30% wood powder, which shows an increase of about 15% compared to the composite made with 40% wood powder and compared to the composite made with 20% wood powder shows an increase of about 25%.

4.3 The mutual effect of the type of PVC and the amount of wood powder on the bending strength of the sample

Table 4, obtained from the variance analysis of the bending test of the samples, shows that the interaction effect of the type of PVC and the amount of wood powder on this resistance is not significant at the 1% level (** is Significance at the 1% level, and NS is a Lack of meaning). Duncan’s test was used to compare and group the averages, and the results can be seen in Fig. 3.

The highest bending strength value is related to

Table 4 Variance analysis of flexural strength test

Sources Change	Degrees of freedom	Sum of squares	Average of squares	F Computational	Probe Level
The effect of the amount of wood powder	2	11.5	5.7	17.83	0.000**
The effect of the amount of PVC	2	67.34	33.9	102.43	0.000**
Interaction between powder and PVC	4	1.2	0.3	24	0.449NS
Error	16	4.98	0.32	-	-
Total	24	86.1	-	-	-

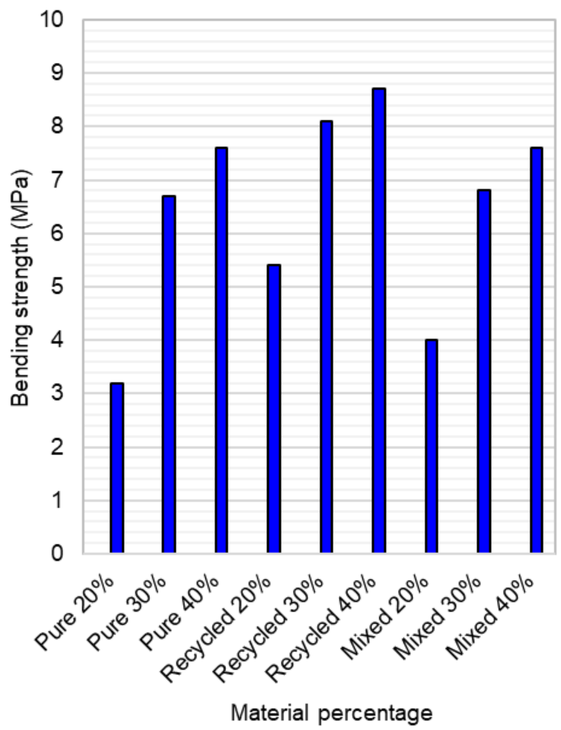

Fig. 3 Mutual effect of wood powder and PVC on ben ding strength

Table 3 The effect of PVC type on composite bending strength and its grouping by Duncan's method

PVC type	Bending strength (MPa)	Duncan grouping (level 1%)
A	3087.3	Pure
B	462.54	Recycled
C	6040.5	Mixed

composites made with recycled PVC and 40% wood content, and the lowest bending strength is related to samples made of pure PVC and wood powder, 20%. Because PVC is recycled and the presence of impurities in its composition and the filling property of wood powder has made the samples flat, the highest resistance is related to recycled PVC with 40% wood.

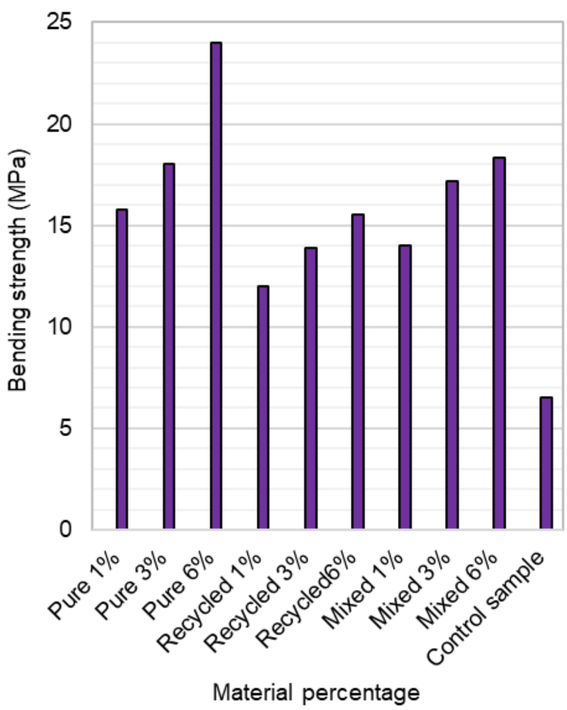

Fig. 4 Mutual effect of nanoclay and PVC on bending strength

The independent effect of PVC type on the modulus of elasticity was significant at the 1% level. Furthermore, the averages were compared through Duncan's test, shown in Table 5. The highest modulus of elasticity is related to the composite made with mixed PVC, which shows an increase of about 3% compared to recycled PVC and about 89% compared to pure PVC.

The amount of modulus of elasticity related to the composites made with PVC and the amount of wood powder was also investigated. The results showed that the highest value of the modulus of elasticity was related to the composite made with pure PVC, and the amount of wood was 40%. The lowest value was related to recycled PVC, and the amount of wood was 20%.

4.4 Interaction effect of PVC type and nanoclay amount on bending strength of samples

The interaction effect of PVC type and amount of nano clay on bending strength is not significant at the level of 1%. The results of Duncan's test and the comparison of averages show that the highest resistance is related to pure PVC and nano clay 6%, and the lowest value is related to Recycled PVC and nanoclay 1% (Fig. 4).

4.5 The interaction effect of the type of PVC and the amount of wood powder on water absorption after 72 hours of immersion

The amount of water absorption after 72 hours of immersion of the samples shows that the interaction effect of these two substances is insignificant at 1%. The highest amount of water absorption was related to the composite

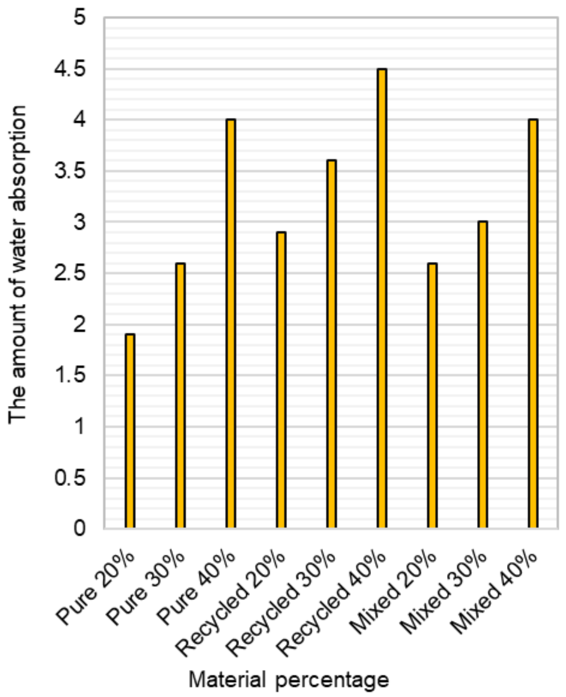

Fig. 3 Mutual effect of wood powder and PVC on ben ding strength

made with recycled PVC, and the amount of powder was 40%. The lowest was related to the composite containing pure PVC, and the amount of powder was 20%. With the increase of wood powder, the surface area of the particles has increased and increased water absorption (Fig. 5).

5. Conclusions

This research concentrated on the formulation of polyvinyl chloride (PVC)-based nanocomposites augmented with plantain wood powder and nano clay, with the objective of improving the mechanical characteristics of materials intended for sports equipment. The results demonstrated significant improvements in essential performance metrics, including bending strength, modulus of elasticity, and water absorption resistance, consistent with the aims specified in the title, abstract, and keywords of this publication. The findings indicated that the kind of PVC, the quantity of plantain wood powder, and the addition of nano clay significantly influence the mechanical characteristics of the composites. Mixed PVC, including recycled and virgin materials, had the greatest bending strength owing to its stiffness, whilst pure PVC offered enhanced flexibility and moisture resistance. Optimal reinforcing was reached with 30% plantain wood powder, which resulted in a 25% increase in bending strength over lesser concentrations. Furthermore, the use of nano clay boosted elastic modulus and bending resistance, addressing the durability and flexibility limitations of existing materials. Water absorption tests validated the superior resilience of the produced composites, affirming its appropriateness for use in various climatic circumstances. Composites composed of 100% PVC and 20% wood powder exhibited the minimal water absorption, making them suitable for applications necessitating superior moisture resistance. The findings emphasize the promise of the proposed nanocomposite as a lightweight, long-lasting, and environmentally friendly replacement for existing materials used in protective equipment, helmets, and sports gear. This work efficiently addressed inadequacies in conventional sports equipment materials by introducing a novel PVC-based nanocomposite that balances mechanical strength, flexibility, and environmental sustainability.

The material's biodegradability and cost-efficiency bolster worldwide initiatives for sustainable manufacturing techniques. Future research may investigate further reinforcements, processing methodologies, or applications to fully use the capabilities of these composites in revolutionizing the sports equipment sector. This research advances materials science and underscores the revolutionary influence of nanotechnology on the quality and safety of sports equipment.

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