Preparation and Performance Study of Carbon Fiber Composite Electroplated Carbon Badminton Racket

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Driven by the slogan of "Fitness for All", more and more people are participating in sports, which also promotes the popularity of the sports equipment market, of which badminton rackets are an important part. With the improvement of people’s economic level, there are higher requirements for the materials of various sports equipment. It is expected that badminton rackets will not only be light, but also bearable, and the electroplated carbon in carbon fiber composites has such properties. Therefore, the purpose of this paper is to study the preparation of badminton rackets by electroplating carbon with carbon fiber composite materials and to study its performance. In this paper, the properties of carbon fiber composites are tested and analyzed, and the relevant chemical formulas are used to explain them. The experimental results of this paper show that after using the same pressure to conduct experiments on wooden, iron, steel, steel-aluminum, carbon-aluminum, and carbon bats, it is found that the bearing capacity of wooden bats is only 28%, the damage degree of badminton racket is 54%, while the bearing capacity of carbon racket is 89%, and the damage degree of badminton racket is 12%. This fully shows that the badminton racket made of electroplated carbon material not only has a much higher bearing capacity than badminton rackets of other materials, but also has a much lower damage degree than badminton rackets of other materials. Therefore, badminton rackets made of electroplated carbon are more durable and more popular.

1. Introduction

The demand for high-performance composite materials, especially in the fields of defense, military, and aerospace, has contributed to the rapid development of science and technology. Carbon fiber composite material is one of the most widely used composite materials, and the properties of carbon fiber directly determine the properties of the composite material. Scientific researchers in various countries have conducted many studies on the composition and structure of carbon fibers and their properties. Since the beginning of the twenty-first century, the properties of carbon fibers have been continuously optimized and improved, and the research on the manufacturing process of composite materials has also deepened, striving to make composite materials more efficient and simpler to manufacture.

A further study of carbon fiber materials is the study of their composite materials. In the molding process of carbon fiber composite materials, including hand molding and stretching. The resin conveying molding process is to perform the reinforcement material into a closed shape and solidify it under vacuum and pressure conditions. This process is simple and convenient and is widely used. In the aerospace field, in addition to the excellent properties of the composite material itself, it is also found that the carbon fiber composite material containing some shape memory effect maintains the shape memory ability.

The innovations of this paper are as follows: (1) This paper introduces the theoretical knowledge of carbon fiber composite materials and electroplated carbon and uses carbon fiber composite material and electroplated carbon to analyze how carbon fiber composite material and electroplated carbon play a role in the preparation and performance research of badminton racket. (2) This paper expounds the properties of carbon fiber materials and electroplated carbon. It is found through experiments that the
badminton rackets made of carbon fiber materials and electroplated carbon are of better quality and more popular.

2. Related Work

With the increasing emphasis on sports in China, the number of people participating in sports is also increasing rapidly. Mizuno found that people developed fully automatic badminton robots that could catch and serve in the same environment as a human badminton player. In the system he invented, the robot could automatically move to where the shuttlecock would fall and hit it back with a normal badminton racket. Mizuno gave a general introduction to a fully automatic badminton robot, but did not describe it with a practical example [1]. Park believes that shoulder and elbow injuries account for a considerable proportion of injuries in badminton. Because badminton requires repetitive, high-velocity overhead movements that place high loads on the upper body joints, badminton players often experience shoulder and elbow pain and decreased function. His research is mainly to introduce to a fully automatic badminton robot, but did not describe it with a practical example [1]. Park believes that shoulder and elbow injuries account for a considerable proportion of injuries in badminton. Because badminton requires repetitive, high-velocity overhead movements that place high loads on the upper body joints, badminton players often experience shoulder and elbow pain and decreased function. His research is mainly to introduce to a fully automatic badminton robot, but did not explain the process of the whole experiment, resulting in no corresponding conclusions [2]. Duncan’s study examines the impact of changes in physical and psychological arousal on badminton short serve performance in competitive and practice environments. He experimented with 20 badminton players (10 males and 10 females), with short serve measured at rest, midway, and end of a badminton-specific training program. The results showed that the performance of the short serve in practice was significantly better compared to the game, while the performance of the short serve in the real game was not very good. This is because in the real game, the athlete will have anxiety and tension, which will affect the performance. Although he conducted experiments on 20 athletes and analyzed the results of the experiments, there was no solution to the experimental results [3]. Minkai found that despite the well-known importance of badminton in sports, badminton is poorly defined and lacks research. In contrast to general training typically used to improve a badminton player’s on-court agility, Reactive Initiation Training (RIT) challenges perceived speed, requiring only quick steps in the direction of the shuttlecock. His research explores comparing the speed of body reflexes to reaction initiation exercises to determine whether these exercises are effective in improving on-court agility. 20 badminton novices were divided into two halves and received physical reaction speed and reaction initiation training on the court. Before and after training, they took on-court agility tests with pre-judgment and without pre-judgment. The results showed that both training methods reduced the average running time, but only the reaction initiation training additionally reduced initiation time and its proportion in those time-consuming positions. He designed and practiced the process of the whole experiment, but there is no specific experimental data to prove the authenticity of the experiment [4]. Yuan found that the loading of gold nanoparticles (AuNPs) onto environmentally sensitive polymer microgels is increasingly used to tune their optical properties and catalytic activities. Here, he synthesized composite polymer microgels with a core-shell structure and controllably loaded AuNPs onto the network chains of the polymer microgels. The results show that the prepared AuNPs composites have good pH sensitivity; thus, the electromagnetic coupling between AuNPs can be regulated by polymer microgels under various acidic conditions. But he did not explain in detail why this study was done [5]. Akhtar discovered that cellulose, a natural biopolymer commonly used as a support agent, has enhanced applicability and properties. The cellulose he isolated from the waste was used for silver nanoparticle (Ag-NPs) impregnation by a simple and reproducible method. Cellulose (Ag-Cel) prepared from Ag-NPs was characterized by powder X-ray diffraction, Fourier transform infrared spectroscopy, and scanning electron microscopy. Its thermal stability was investigated by thermogravimetric analysis. Although the scholar has carried out detailed experiments, no corresponding conclusions have been drawn [6].

3. Test Method of Carbon Fiber Composite Material Electroplating Carbon Performance

3.1. Application of Carbon Fiber Composite Materials. In carbon fiber composites, if the carbon fibers in the matrix are stretched along the fibers, the strain capacity of all fibers is the same, and some fibers will not affect the effect of other fibers after failure [7]. The broken fibers did not play a role, but the other fibers played their part as usual. According to this characteristic, if the material is damaged, especially in the use of sports equipment, it will not cause serious performance degradation. According to this characteristic, the personal safety of the athlete can be ensured [8].

Badminton is a sport suitable for all ages. In sports, the hardness and durability of badminton rackets have a great influence on the sports performance [9]. For example, some sub-rackets are prone to breakage, which can affect an athlete’s level. The structure diagram of the badminton racket made of electroplated carbon material is shown in Figure 1.

As shown in Figure 1, with the development of science and technology, electroplated carbon badminton rackets have appeared in the sporting goods market. Carbon fiber has the characteristics of high hardness and toughness. In specific applications, carbon fiber and other substances are usually combined to form carbon fiber composite materials [10]. At the same time, the electroplated carbon should have excellent mechanical properties after curing, and in addition, it should have good fluidity, which is convenient for curing and molding. The application fields of carbon fiber composite materials are shown in Figure 2.

As shown in Figure 2, in the structure of carbon fiber composites, fiber reinforcement takes on the heavy
responsibility of the mechanical properties of the composites. The electroplated carbon is responsible for the task of fixing and strengthening and protects the carbon fiber from damage from the external environment. Therefore, the electroplated carbon and carbon fiber reinforcement of composite materials need to have excellent wettability and adhesion \[11\]. The good performance of carbon fiber self-recovery after deformation is shown in Figure 3.

As shown in Figure 3, the performance of the composite material depends on the ratio of reinforcement to matrix and the performance of the individual components. The general reinforcing materials are carbon fibers, glass fibers, plastic fibers, etc. In addition to metals, ceramics, and other materials, the matrix is mainly a resin material. Reinforcing materials can increase material strength and improve mechanical properties \[12\].

3.2. Characteristic Analysis of Electroplated Carbon in Carbon Fiber Composites. In the process of glass transition of electroplated carbon, the mechanical properties of the resin will be quite different before and after. As the ambient temperature gradually increased, the free volume of the electroplated carbon molecules began to expand. When the temperature reaches the glass transition temperature, the free volume of the electroplated carbon molecules is sufficient, so the configuration of the electroplated carbon molecules is fully changed and adjusted, and the movement of the molecular chain is very active \[13\]. The analysis of electroplated carbon with different formulations is shown in Figure 4.

As shown in Figure 4, because the #20 formula has too little electroplating carbon, the performance in the DMA test is not ideal. Therefore, in the DSC test, it is no longer necessary to test the #20 type electroplated carbon, and only the DSC test of the #40, #60, and #80 samples is required. The three proportioned samples were scanned at different constant heating rates, and the apparent activation energy \(E_a\) was calculated according to the Kissinger formula; apparent activation energy can give a clearer physical meaning to elementary reactions, that is, the difference between the average
It can be seen from Table 2 that solidification is a Chinese word, which chemically refers to the process of transforming substances from low molecules to high molecules, and also refers to the process of forming certain fixed views and viewpoints on things [16]. When the specific gravity of electroplating carbon increases, both $E_a$ and $A$ of the curing reaction of the system will increase. This is because the energy required for the electroplating carbon homopolymerization reaction is larger than the other two curing reactions [17]. With the increase of carbon content in electroplating, the difference between #60 and #80 is an order of magnitude from #40, while the difference between #60 and #80 is not obvious, indicating that the addition of electroplating carbon can prolong the service life of the mixed resin [18]. Electroplating carbon under different vision is shown in Figure 5.

As shown in Figure 5, the ability of a metallic material to resist permanent deformation or fracture under static load, and it can also be defined as proportional limit, yield strength, breaking strength, or ultimate strength. In order to ensure the full progress of the curing reaction, the curing temperature needs to be higher than the glass transition temperature, which can ensure good mechanical properties and curing degree of the electroplated carbon after curing [19].

3.3. Density Test. In this paper, the method of electroplating is used to electroplate the carbon fiber with nickel, and the metallization modification is carried out. The effect of nickel on the wettability of the carbon fiber interface was investigated by observing the high temperature spheroidization of the copper plating layer during the heat treatment process. By testing the thermal shock resistance of the carbon fiber composite wire, the bonding force between the carbon fiber and the copper coating was studied [20].

Archimedes’ principle generally refers to Archimedes’ law. An important principle of hydrostatics, which states that an object immersed in a stationary fluid, experiences a buoyant force equal to the weight of the fluid displaced by the object, directed vertically upward and through the centroid of the displaced fluid [21]. The actual density of carbon fiber copper composites is measured using Archimedes’ principle:

$$ F = p g v $$

$p$ represents the density of distilled water and $g$ represents the volume of distilled water displaced by immersion of the composite in distilled water. The volume $V$ of the composite material at this time is

$$ V = \frac{m_1 - m_2}{p} $$

Then, the density $p$ of the composite material is

$$ p = \frac{m_1 p}{m_1 - m_2} $$

The corresponding peaks of the three exothermic peaks in the DSC scan at different heating rates are shown in Table 1.

As shown in Table 1, the second exothermic peak disappeared when the temperature increased. Because the reaction rate was too fast, the reaction was not sensitive enough to temperature, so it was incorporated into the third peak, which was used to test the viscosity of electroplated carbon as a function of temperature using the temperature ramp mode of rotational rheology. The time-sweep mode was used to test the relationship between the viscosity and time of electroplated carbon at a constant temperature [15]. The kinetic parameters of the curing reaction are shown in Table 2.
Then, the density $\rho_r$ of the composite material is

$$\rho_r = \frac{\rho_1}{\rho_2}$$  \hspace{1cm} (7)$$

Among them, $\rho_1$ is the actual density of the composite material, and $\rho_2$ is the theoretical density of the composite material.

3.4. Test of Thermal Conductivity. Raman spectroscopy is a type of scattering spectroscopy. Raman spectroscopy is an analysis method of Raman scattering effect, which analyzes the scattering spectrum with different frequencies from the incident light to obtain information on molecular vibration and rotation, and is applied to the study of molecular structure. Raman spectroscopy is an important means to study the structure of carbon materials, which reflects the changes in the structure of carbon materials from the perspective of chemical structure [22]. The thermal conductivity $K$ is measured by a laser thermal conductivity meter, and the thermal conductivity calculation formula is

$$K = \alpha \cdot \rho \cdot C_p$$ \hspace{1cm} (8)$$

where $K$ is the thermal conductivity, $\alpha$ is the thermal diffusivity, $\rho$ is the density, and $C_p$ is the specific heat capacity.

In recent decades, many outstanding research results have emerged in China in the field of materials, among which carbon fiber composite materials have been widely used in modules ranging from module shells and cabinets to aircraft fuselages [23]. However, how to objectively and quantitatively evaluate the electromagnetic pulse protection performance of this new type of composite material, such as the radio frequency impedance characteristics of the composite material, the electrical conductivity of the composite material under the action of a magnetic field, and the impedance characteristic of the composite material under the action of lightning pulse, it involves multidisciplinary knowledge such as mechanical structure, electromagnetic field propagation, instrument measurement, and materials. At present, there are not many people engaged in research in this field in China, which restricts the development and improvement of new materials [24].

3.5. Nickel Electroplating and Electroplating Carbon on Carbon Fiber Surface. The pretreated carbon fibers are electroplated with nickel. The carbon fiber content in the plating solution was kept at about 0.2 g/L, and the short carbon fibers were put into the nickel plating solution for ultrasonic
stirring. When the short carbon fibers are all settled on the bottom cathode copper plate, the power is turned on, and the thickness of the nickel layer is controlled by the electroplating time. The reaction that occurs at cathode Ni during nickel plating is

\[ \text{Ni}^{2+} + 2e = \text{Ni} \] (9)

The main reaction that occurs at anode Ni is

\[ \text{Ni} - 2e = \text{Ni}^{2+} \] (10)

If the anode current density is too large, anode passivation is likely to occur, accompanied by the progress of the side reaction \( O_2 \) as

\[ 2H_2O - 4e = O_2 + 4H^+ \] (11)

Therefore, in the process of electroplating, the current density is strictly controlled to ensure the quality of the coating.

The nickel-plated carbon fibers were repeatedly ultrasonically cleaned with distilled water, and then copper-plated. The carbon fiber content in the plating solution was maintained at about 0.4 g/L. When the nickel-plated carbon fibers were ultrasonically stirred in the solution, the power was turned on. The temperature of the plating solution was 40°C and the current density was 2.5 A/dm. The reaction that occurs at cathode Cu during copper plating is

\[ \text{Cu}^{2+} + 2e = \text{Cu} \] (12)

The main reaction that occurs at anode Cu is

\[ \text{Cu} - 2e = \text{Cu}^{2+} \] (13)

In the process of copper plating, it is still necessary to control the current density. Excessive current density will also be accompanied by side reactions.

The electroplated copper-plated and nickel-plated copper carbon fibers were taken out, repeatedly washed with distilled water for 3 times, then filtered and cleaned with anhydrous alcohol on a suction filter, and finally placed in a vacuum drying box for drying.

Since metal is easily oxidized in the air, it is inevitable that some coatings will be oxidized to form oxides during the cleaning and drying process of carbon fibers. The coating of the oxide is relatively poor, which will affect the subsequent experiments, so the copper oxide must be reduced. The carbon fiber is put into a vacuum tube furnace for reduction, and the reaction that occurs is

\[ H_2 + \text{CuO} \rightarrow H_2O \] (14)

Electroplating time is an important factor to control the thickness of the coating, and the method of determining the thickness of the carbon fiber surface layer by metallographic method is difficult to implement. Therefore, this paper uses the weighing method to estimate the average thickness of the coating. The weighing method is the method recommended by the International Organization for Standardization. It is only suitable for gases that do not react between components, components and the inner wall of the cylinder, and condensable components that are completely gaseous under experimental conditions. The calculation formula of the average thickness of the coating is

\[ \Delta r = \left( \sqrt{1 + \frac{\rho_G \Delta G}{\rho_{cNi}G}} - 1 \right) d \] (15)

In the formula, \( \Delta G \) is the weight gain rate of carbon fiber before and after nickel electroplating; \( \rho_c \) and \( \rho_{cNi} \) are the density of carbon fiber and nickel, respectively; and \( d \) is the diameter of carbon fiber.

Many studies have shown that there are two main factors that affect the thermal shock resistance of coatings. The first is the difference between the thermal expansion coefficient of the coating and the base material. The thermal expansion coefficient of the metal copper coating is larger, while the thermal expansion coefficient of the matrix carbon fiber is smaller. Due to the difference in thermal expansion coefficient, thermal stress will be generated between carbon fiber and copper during the cooling and heating cycle. The calculation formula of thermal stress is

\[ \sigma_{th} = \frac{E_f}{1 - \nu} \cdot (\alpha_r - \alpha_s) \cdot (T_s - T_r) \] (16)
In the formula, \( \alpha_r \) and \( \alpha_s \) are the thermal expansion coefficients of the substrate and the coating, respectively, and \( T_s \) and \( T_r \) are the temperatures of the coating and the substrate, respectively. It can be seen from the formula that the smaller the thermal expansion coefficient between materials, the smaller the thermal stress will be. The greater the interfacial bonding strength, the better the thermal shock resistance of the coating.

Since carbon fiber is a carbon material, it has a lower theoretical specific capacity \( ae^- \). In general, researchers improve the actual cycle \( Li_xC \) of carbon fibers through surface modification, biological preparation of carbon fibers, etc., so that it can approach the theoretical capacity to the greatest extent:

\[
aLi^+ + C(\text{carbonfiber}) + ae^- \leftrightarrow Li_xC
\]  

4. Experiment and Analysis of Carbon Fiber Composite Material Electroplating Carbon

4.1. Experiment and Analysis of the Properties of Carbon Fiber Composites. In many sports, athletes hope that the equipment can meet the characteristics of lightweight and high strength at the same time, while the density of carbon fiber composite materials is only 1.76 to 1.80 \( g/cm^3 \), and the density of metal materials is several times that of carbon materials. For example, steel has a density of 7.87 \( g/cm^3 \) and aluminum has a density of 2.7 \( g/cm^3 \). These materials do not meet certain special sports needs. The application of carbon fiber composite materials in sports equipment is shown in Figure 6.

As shown in Figure 6, therefore, the carbon material is lightweight and high in strength and is very suitable for use in sports equipment. Carbon materials are widely used in some sports such as bicycles, sailboats, poles, golf, and rackets. The physical properties of different reinforcing materials and the comparison of badminton rackets made of different materials are shown in Table 3 and Table 4.

As shown in Table 3, carbon materials have high fatigue resistance compared with metals and are very suitable for the manufacture of large rackets. As the competition in
sports becomes more and more intense, the requirements in the field of rackets are also increasing.

As shown in Table 4, the interface problem of metal matrix composites has always been a hot and difficult problem in research, and the bonding state between the interfaces has an important impact on the performance of the composites. The interface between carbon fiber and copper has high interfacial energy, which will lead to poor wettability between carbon fiber and copper. This poor wettability results in the simple mechanical bonding of the interface between carbon fiber and copper, and it is difficult to prepare carbon fiber composites with good interfacial bonding, which limits its performance.

The sintering temperature also has a great influence on the thermal conductivity of the composites, and the thermal conductivity changes with the increase of the sintering temperature, and the density is the same. With the increase of sintering temperature, the thermal conductivity first
increases and then decreases and reaches the maximum value at 950°C. The effect of sintering temperature on the composites is shown in Figure 7. It can be seen from Figure 7 that when the test temperature is relatively low, the thermal expansion difference between the composite materials formed by different sintering temperatures is very small, and as the test temperature increases, the difference becomes larger and larger. The average thermal expansion of the samples sintered at 950°C is the largest, and the average thermal expansion of the samples sintered at 850°C is the smallest.

It can be seen from Figure 7 that the density has an important influence on the thermal conductivity of the composite material; the higher the density \( \rho \), the higher the thermal conductivity of the material. The effect of porosity \( \lambda \) on composites is

\[
\lambda = \lambda_s (1 - \rho) \quad (18)
\]

The relationship between the expansion ratio and temperature of the composites with different carbon fiber volume fractions is shown in Figure 8.

It can be seen from Figure 8 that with the increase of the volume fraction of carbon fibers, the expansion rate of the composite material shows a decreasing trend. Objects expand and contract due to changes in temperature. The change in length magnitude caused by a unit temperature change is expressed by the thermal expansion coefficient. When the volume fraction of carbon fiber volume fraction increases, the thermal expansion coefficient of the composite becomes smaller. On the other hand, the addition of carbon fiber to the matrix will form the interface and internal stress, which will affect the thermal expansion of the composite. With the increase of carbon fiber content, the interface and internal stress will increase, and the influence on thermal

| Material                  | Pressure | Affordability | Level of damage |
|---------------------------|----------|---------------|-----------------|
| Wooden racket             | 30       | 28%           | 54%             |
| Iron beat                 | 30       | 32%           | 58%             |
| Steel and aluminum racket | 30       | 40%           | 43%             |
| Carbon aluminum racket    | 30       | 65%           | 28%             |
| Carbon racket             | 30       | 89%           | 12%             |

Figure 9: Bearing capacity of badminton rackets of different materials under the same force. (a) Bearing capacity of badminton racket made of ordinary material. (b) Bearing capacity of badminton racket made of electroplated carbon material.
expansion will be greater, so the thermal expansion coefficient will also decrease.

Direct electroplating-hot pressing is a good method for preparing short carbon fiber composites. Carbon fibers overlap each other in the process of electroplating and maintain uniform dispersion in the subsequent cleaning, drying, and hot pressing processes and can prepare composite materials with uniform distribution of carbon fibers.

4.2. Experiment and Analysis of Electroplated Carbon Badminton Racket. After the electroplated carbon badminton racket is produced, its durability needs to be tested through actual use. Hardness, bearing capacity, etc. all need to be verified. In order to enhance the scientificity of the test, this paper conducted an experiment on a badminton coach to let him use badminton rackets of different materials and test the endurance of badminton rackets under the same force, so as to compare their hardness and draw conclusions. The bearing capacity of badminton rackets of different materials under the same force is shown in Figure 9.

As shown in Figure 9, when testing the flexibility, mechanical bending equipment can be used to apply pressure to badminton rackets of different materials and compare their ability to withstand the same pressure. In this paper, experiments were carried out on wooden, iron, steel, steel-aluminum, carbon-aluminum, and carbon bats, as shown in Table 5.

As shown in Table 5, the bearing capacity of wooden, iron, steel, steel-aluminum, carbon-aluminum, and carbon beats under the same pressure was analyzed. It is found that only the carbon racket has a relatively high bearing capacity and a relatively low degree of damage, so now the mainstream material of the racket is mainly carbon racket. The racket made of this material is of good quality and light weight, which can make athletes swing faster and use less effort. Due to the influence of other factors, such as users, use environment, and frequency of use, the results of this experiment are not completely reliable, and there are certain differences.

5. Conclusions

With the development of science and technology, people’s quality requirements for various things are getting higher and higher. The development of China’s aviation industry is inseparable from the contribution of carbon fiber composite materials. Carbon fiber composites have been widely used in many fields because of their good properties. This article first gives a general introduction to carbon fiber composite materials and electroplated carbon so that people can understand the properties and principles of the two and then use the relevant chemical formulas to analyze their properties. Finally, it is found that both have super-strength properties. In the experimental part, this paper compares the physical properties of electroplated carbon and different reinforcing materials and draws the conclusion that the fatigue strength of carbon fiber composites is much higher than that of metal materials. Then, the hardness and bearing capacity of electroplated carbon badminton rackets were compared. Under the same force and pressure, the electroplated carbon badminton racket is not only more durable, but also harder than other badminton rackets. Therefore, it is very necessary to study the preparation and performance of electroplated carbon badminton rackets.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] N. Mizuno, T. Makishima, K. Tsuge, S. Kondo, and S. Yamakawa, “Development of automatic badminton playing robot with distance image sensor,” IFAC-PapersOnLine, vol. 52, no. 8, pp. 67–72, 2019.
[2] J. Park, Y. H. Lee, I. D. Kong, J. S. Chang, T. Kim, and H. C. Lee, “Ultrasonographic changes of upper extremity tendons in recreational badminton players: the effect of hand dominance and comparison with clinical findings,” British Journal of Sports Medicine, vol. 51, no. 4, pp. 370.1–37370, 2017.
[3] M. J. Duncan, C. Chan, N. D. Clarke, M. Cox, and M. Smith, “The effect of badminton-specific exercise on badminton short-serve performance in competition and practice climates,” European Journal of Sport Science, vol. 17, no. 2, pp. 119–126, 2017.
[4] M. Dong, J. Lyu, T. Hart, and Q. Zhu, “Should agility training for novice badminton players be physically or perceptually challenging?,” The Journal of Sports Medicine and Physical Fitness, vol. 59, no. 12, pp. 2015–2021, 2019.
[5] Z. Yuan, Z. Jia, Y. Gao, and Z. Ying, “Controllable synthesis of P(NIPAM-co-MPTMS)/PAA–Au composite materials with tunable LSPR performance,” Journal of Materials Science, vol. 52, no. 16, pp. 9584–9601, 2017.
[6] J. Akhtar, A. Ali, I. Haq, J. Akhtar, and M. Zia, “Synthesis of ag-NPs impregnated cellulose composite material: its possible role in wound healing and photocatalysis,” IET Nanobiotechnology, vol. 11, no. 4, pp. 477–484, 2017.
[7] N. Lewis and D. Nocera, “Powering the planet: chemical challenges in solar energy utilization,” Proceedings of the National Academy of Sciences of the United States of America, vol. 103, no. 43, pp. 15729–15735, 2006.
[8] B. M. Dobratz, “Properties of chemical explosives and explosive simulants,” Lbl Explosive Handbook, vol. 51, no. 3–4, pp. 339–340, 2018.
[9] W. A. Rutala and D. J. Weber, “Infection control and hospital epidemiology disinfection of endoscopes: review of new chemical sterilants used for high-level disinfection,” Infection Control and Hospital Epidemiology, vol. 20, no. 1, pp. 282–288, 2017.
[10] Y. Zhang, X. Zhao, X. Zhang, and J. Sun, “The influence of chemically enhanced backwash by-products (CEBBPs) on water quality in the coagulation–ultrafiltration process,” Environmental Science and Pollution Research, vol. 23, no. 2, pp. 1805–1819, 2016.
[11] T. Murata and J. Batkhuu, “Biological activity evaluations of chemical constituents derived from Mongolian medicinal forage plants and their applications in combating infectious diseases and addressing health problems in humans and livestock,” *Journal of Natural Medicines*, vol. 75, no. 4, pp. 729–740, 2021.

[12] S. Baeckens, K. Huyghe, R. Palme, and R. V. Damme, “Chemical communication in the lacertid lizard Podarcis muralis: the functional significance of testosterone,” *Acta Zoologica*, vol. 98, no. 1, pp. 94–103, 2017.

[13] J. Brunink, J. R. Haak, J. G. Bomer, D. N. Reinhoudt, M. A. Mckervey, and S. J. Harris, “Chemically modified field-effect transistors; a sodium ion selective sensor based on calix[4]arene receptor molecules,” *Analytica Chimica Acta*, vol. 254, no. 1-2, pp. 75–80, 1991.

[14] Y. Zhang, Y. Li, and C. Bai, “Microstructure and oxidation behavior of Si-MoS2 functionally graded coating on Mo substrate,” *Ceramics International*, vol. 43, no. 8, pp. 6250–6256, 2017.

[15] M. Hayyan, M. A. Hashim, and I. M. Alnashef, “Superoxide ion: generation and chemical implications,” *Chemical Reviews*, vol. 116, no. 5, pp. 3029–3085, 2016.

[16] L. Zeng, J. Shi, J. Luo, and H. Chen, “Silver sulfide anchored on reduced graphene oxide as a high-performance catalyst for CO2 electroreduction,” *Journal of Power Sources*, vol. 398, pp. 83–90, 2018.

[17] T. P. Guinee and P. F. Fox, “Salt in cheese: physical,” *Chemical and Biological Aspects. Cheese*, vol. 1, no. 4, pp. 317–375, 2017.

[18] M. N. Bhuiyan, J. U. Chowdhury, and J. Begum, “Chemical investigation of the leaf and rhizome essential oils of Zingiber zerumbet (L.) Smith from Bangladesh,” *Bangladesh Journal of Pharmacology*, vol. 4, no. 1, pp. 9–12, 2017.

[19] S. Szopa, B. Aumont, and S. Madronich, “Assessment of the reduction methods used to develop chemical schemes: building of a new chemical scheme for VOC oxidation suited to three-dimensional multiscale HOx-NOx-VOC chemistry simulations,” *Atmospheric Chemistry and Physics Discussions*, vol. 5, no. 1, pp. 2519–2538, 2017.

[20] T. Ruedas and D. Breuer, “On the relative importance of thermal and chemical buoyancy in regular and impact-induced melting in a Mars-like planet,” *Acta Materialia*, vol. 51, no. 16, pp. 4679–4691, 2017.

[21] L. Zeng, X. P. Guo, G. A. Zhang, and H. X. Chen, “Semiconductivities of passive films formed on stainless steel bend under erosion-corrosion conditions,” *Corrosion Science*, vol. 144, no. 1, pp. 258–265, 2018.

[22] M. Romaniello, F. Primas, M. Mottini, M. Groenewegen, G. Bono, and P. Francois, “The influence of chemical composition on the properties of Cepheid stars,” *Astronomy & Astrophysics*, vol. 488, no. 2, pp. 731–747, 2008.

[23] T. Hueckel, M. Ciantia, B. Mielniczuk, M. S. El Youssoufi, and L. B. Hu, “Modeling physico-chemical degradation of mechanical properties to assess resilience of geomaterials,” *Journal of Non-Crystalline Solids*, vol. 27, no. 2, pp. 273–283, 2017.

[24] J.-H. Lee and E.-J. Jae-Moon, “A study on the recognition of badminton brand using big data analysis,” *Korean Journal of Sport Science*, vol. 26, no. 3, pp. 125–137, 2017.