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Article

Risk control of sports flooring in athletic activities from the perspective of inertia mechanics

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Abstract: From the perspective of inertia mechanics, sports flooring plays a critical role in controlling safety risks in athletic activities. Firstly, high-quality flooring materials and structural designs can effectively absorb impact forces generated during exercise, thereby reducing the physical burden on athletes and lowering the risk of injury. Secondly, flooring materials with good resilience can provide appropriate rebound properties, offering better support and reaction forces for athletes, thus improving both performance and safety. Additionally, high-quality flooring materials possess high durability and stability, maintaining their performance over prolonged use and minimizing safety hazards caused by material degradation. Lastly, flooring design should account for the characteristics of different sports, providing suitable coefficients of friction and elasticity to meet the needs of various athletes and reduce the likelihood of accidents during sports activities. Therefore, the design and material selection of sports flooring play an essential role in ensuring athlete safety and enhancing athletic performance. The findings of this study have significant implications for future research and practical applications, as they provide a scientific basis for the development of safer, more effective sports flooring solutions that can be tailored to meet the specific needs of different sports disciplines.

Keywords: sports injuries; inertia mechanics; athletic activities; accident risk; sports flooring

1. Introduction

With the popularization and professionalization of sports, the safety and performance of athletes have become focal points of attention. During sports activities, athletes are prone to various forms of injuries due to high intensity and frequent movements. To mitigate these risks, researchers and engineers have dedicated efforts to developing and optimizing sports flooring materials and designs. This paper aims to examine how advancements in sports flooring materials and design can enhance athlete safety and performance, providing a comprehensive analysis of the current state and future directions of this critical area.

1.1. Requirements for sports flooring

Different materials, like wood, polyurethane, and rubber, have unique qualities that affect how well sports flooring absorbs shock and rebounds. By testing these materials under various conditions, we can identify the best ones for sports flooring. Using the principles of inertia mechanics helps us understand the forces athletes experience. Through mechanical analysis, we can design flooring that absorbs impact while providing support. Studying the body’s movements during sports helps us understand what different sports require from flooring. Ergonomic studies guide us in designing flooring that better supports athletes' movements, reducing injuries [1]. Testing on actual sports fields, including impact absorption, rebound performance, and durability, ensures the flooring performs well in real use. This paper explores how choosing the right materials and design for sports flooring can improve athlete safety and performance.

1.2. Current status and challenges

Currently, various types of sports flooring are widely used in different sports venues. However, different sports have varying requirements for flooring. For instance, basketball courts require highly elastic flooring for good rebound effects, while gymnastics floors need to have stronger shock absorption properties [2]. Therefore, developing a versatile flooring type that can meet the demands of various sports remains a significant challenge.

Through comprehensive literature reviews and field tests, we aim to analyze the material properties, structural design, and their effects on shock absorption, rebound, durability, and stability of different types of sports flooring [3]. This will help explore ways to optimize sports flooring to reduce sports injuries and enhance the overall sports experience.

2. Risks of floor damage during sports activities

Conventional basketball game-type sports wooden floor court structural parameters:

1) Panel: maple/oak; wooden floor grades are divided into A, B, C and D grades;
2) Bottom layer: multi-layer plywood/solid wood bottom layer; thickness 14–20 mm;
3) Upper keel: Canadian pine; 40 × 60/50 × 80 mm;
4) Lower keel: Canadian pine; 40 × 60/50 × 80 mm;
5) Isolation layer: moisture-proof composite film (non-woven fabric); thickness 0.5 mm;
6) Elastic shock-absorbing pad: made of natural rubber, durable, elastic, environmentally friendly and odorless, with a half-life of 30 years. Installing an elastic pad between the upper and lower keels can solve the noise problem of the floor and improve sports performance.
   Thickness: 10 × 50 × 50 mm/20 × 50 × 80 mm.

2.1. Impact forces

Impact forces are one of the main factors leading to the risk of sports flooring damage. When athletes engage in high-intensity activities such as jumping, running, and rapid stops and turns, the impact forces on the floor significantly increase. These forces are transmitted through the athletes' bodies to the floor, exerting immense pressure on the floor's materials and structure. Particularly, when athletes land at high speeds, the enormous impact forces transmitted in a short period may exceed the floor material's tolerance limits, resulting in cracks, breakage, or dents on the material surface [4]. Furthermore, the stress concentration areas formed by impact forces on the floor may exacerbate the extent of the damage, especially if the floor has minor defects or is aged. Additionally, prolonged repetitive impacts can lead to material fatigue failure, greatly reducing the floor's durability [5]. Therefore, when designing and selecting sports flooring, it is crucial to consider materials with high elasticity modulus and impact resistance to effectively absorb and disperse impact forces, reduce the risk of damage, prolong the lifespan, and ensure athletes' safety and performance. Through mechanical analysis and practical testing, optimizing the floor's structure and materials can significantly enhance its impact resistance and reduce the risk of damage [6].

2.2. The role of friction forces

The role of friction forces is crucial in sports activities, particularly during rapid directional changes or sudden stops, where substantial friction forces are generated between athletes' feet and the floor. These friction forces contribute to surface wear and, over time, can lead to material peeling or damage. Research indicates that different types of sports require varying coefficients of friction to optimize performance and safety [7]. For instance, basketball courts demand a higher coefficient of friction to ensure athletes can make sharp cuts and abrupt stops without slipping, whereas volleyball courts benefit from a moderate coefficient to balance movement control and surface protection. Studies indicate that 12% of basketball injuries occur during pivot movements. The coefficient of friction of sports flooring illustrates whether the surface has excessive friction (which can reduce the flexibility of pivots) or is too slippery (which increases the risk of falls). Considering the mobility and safety of athletes, an optimal coefficient of friction should range between 0.4 and 0.7. The friction coefficient of PVC sports flooring generally maintains within this range, with professional-grade PVC sports flooring having a coefficient of 0.57. This provides adequate and moderate friction, ensuring stability during athletic activities. Moreover, it maintains consistent and regular friction performance in all directions of movement, ensuring that flexibility in movement and pivots is unobstructed. Proper selection of the flooring's friction coefficient is essential, not only to minimize excessive wear but also to enhance athletes' overall performance and safety. By adhering to these considerations, the longevity and functionality of sports flooring can be significantly improved, ensuring it meets the specific demands of various athletic activities.

2.3. Sustained load

Sports flooring frequently endures repeated loads over prolonged periods, significantly affecting its durability. For instance, volleyball courts consistently experience impacts from jumping and running during both training sessions and competitions. Such sustained loads can expedite material fatigue and wear, subsequently escalating the risk of damage. These continuous stresses can lead to microcracks and progressive deterioration of the flooring material, which not only compromises the floor's structural integrity but also poses potential safety hazards to athletes. Moreover, the accumulated strain from these repetitive impacts can reduce the flooring's lifespan, necessitating more frequent maintenance and replacements.

Research has shown that continuous loading cycles lead to material fatigue, which can manifest in microcracks and gradual wear [8]. Over time, these microcracks can expand, leading to significant structural weaknesses that might not be immediately visible but could pose serious risks during high-intensity activities. The cumulative effect of these stresses can compromise the surface's ability to effectively absorb impacts, thus increasing the likelihood of injuries to athletes. Additionally, the type and intensity of the sports activity play a crucial role in how these loads affect the flooring. For example, sports involving heavy landing and quick directional changes tend to exert higher stresses on the flooring compared to less intensive activities. Understanding the effects of sustained loads on sports flooring is essential for designing more resilient surfaces. This helps in selecting materials that offer better durability and shock absorption, and in implementing more robust maintenance strategies to extend the flooring's lifespan, ensuring that the flooring can withstand the rigorous demands of athletic activities while maintaining the safety and performance of the athletes.

2.4. Environmental factors

Environmental conditions such as humidity and temperature fluctuations significantly impact the performance of flooring materials. High humidity levels can cause these materials to absorb moisture and expand, heightening the risk of structural damage [9]. For instance, wood and composite flooring materials exhibit considerable dimensional changes when exposed to varying humidity levels, potentially leading to warping or buckling. Additionally, temperature changes can induce thermal expansion and contraction in flooring materials, resulting in structural stress variations and potential fractures. Such thermal cycling can exacerbate the wear and tear of adhesive bonds in flooring systems, further compromising their integrity. Understanding these environmental effects is crucial for selecting and maintaining flooring materials that can withstand these conditions, ensuring longevity and safety.

2.5. Design and material selection

The design and material selection of flooring are critical factors influencing its damage resistance. High-quality floors often utilize multi-layer structures and premium materials, which are specifically engineered to absorb and disperse the impact forces generated by sports activities. Conducting specific case studies for different sports can help develop tailored flooring solutions [10]. For basketball, researching flooring types that combine elasticity and shock absorption is crucial for high-intensity impacts and quick directional changes. In gymnastics, flooring needs to provide excellent shock absorption and resilience to protect athletes from injuries during landings and tumbles. Volleyball courts require surfaces that offer both shock absorption and energy return to enhance players' performance while minimizing fatigue. For tennis, the flooring should ensure consistent ball bounce and traction to support fast-paced lateral movements. In track and field, multi-layered track surfaces need to provide optimal traction and energy return while reducing the risk of injury. Additionally, considering modular flooring systems that allow customization based on the activity can enable venues to adapt flooring properties to various sports [11]. Multi-layered flooring systems, comprising top comfort layers, middle elastic layers, and supportive base layers, are highly effective in mitigating impact stresses, thereby reducing wear and extending the flooring's lifespan. Selecting materials with superior fatigue resistance, such as advanced polymers and engineered wood composites, can enhance the flooring's durability under repeated loads [12]. Moreover, regular maintenance and upkeep, including periodic inspections and timely repairs of any cracks, dents, or surface wear, are crucial to maintaining the flooring's integrity and performance. Proactive maintenance strategies significantly lower the risk of damage, ensuring a safe and reliable surface for athletic activities.

3. Analysis of athlete injuries caused by inertial forces from floor damage

Analyzing athlete injuries caused by inertial forces from floor damage is a multifaceted process that involves considering various factors such as the extent of floor damage, the athlete's weight, the type of movement, and the angle and speed of the collision. The severity of injuries can vary significantly depending on these parameters [13]. The first step is to assess the specific location and severity of the floor damage, as different types of damage—such as cracks, breakages, or dents—can affect the physical properties of the floor differently. Next, a collision model of the athlete is developed, often using finite element analysis software like Abaqus. This model incorporates detailed simulations of the athlete's movements, and the forces involved during impact [14]. By analyzing the stress distribution and the forces experienced by the athlete during such collisions, researchers can predict potential injuries. For instance, studies have shown that high-speed impacts on damaged floors can result in increased stress concentrations on the athlete's body [7], leading to a higher risk of fractures or soft tissue injuries. Moreover, understanding these dynamics allows for the development of better flooring materials and designs to minimize the risk of such injuries, thereby enhancing athlete safety during sports activities. The following are the detailed analysis steps:

3.1. Analysis of the damaged area

Firstly, it is crucial to identify and assess the location and severity of the floor damage, which can manifest as cracks, breakages, or local dents. These different types of damage impact the physical properties of the floor in various ways (**Figure 1**), affecting the safety of athletes moving on it. Cracks in flooring materials can lead to significant stress concentration areas, increasing the likelihood of further damage under repetitive loads. Breakages and dents can compromise the structural integrity and load distribution capabilities of the flooring, thereby heightening the risk of injuries for athletes. Understanding the specific characteristics and implications of these damages allows for targeted maintenance and repair strategies, ensuring that the sports flooring remains safe and functional [8]. By conducting thorough inspections and employing advanced diagnostic tools, it is possible to accurately evaluate the damaged areas and implement effective interventions to mitigate potential risks.

Figure 1. Potential damage in sports flooring.
Source: https://en.ac-illust.com/clip-art.

3.2. Athlete collision model

Using the Abaqus simulation software, the experiment simulating the collision between athletes and damaged floors during movement includes the following steps: First, create three-dimensional finite element models of both the athlete and the floor, defining their respective material properties such as elastic modulus, Poisson's ratio, and density. Next, establish the contact relationship between the athlete and the floor in Abaqus, setting the athlete's initial position and initial velocity to simulate the athlete's dynamics during movement. Then, define the loading and boundary conditions, applying impact forces to simulate the collision, ensuring the floor remains stable during the collision [15]. During simulation, select an appropriate time step, set dynamic/explicit simulation steps to simulate the entire collision process. In the results analysis phase, focus on the stress distribution and displacement in the athlete model during the collision process to understand the impact forces and stress concentration areas experienced by the athlete. Use the formula F = m · aF = m \cdot a to calculate the impact force, where mm is the athlete's mass, and aa is the acceleration. Subsequently, for an athlete with a mass of 70 kg and an initial speed of 5 m/s, set the time step to 0.001 s for simulation analysis.

3.3. Calculation of impact force

1) Setting the deceleration time tt:
   - Assume the time for the athlete to come to a complete stop during the collision is tt, for example, *t* = 0.1 *t* = 0.1 s.
2) Calculating acceleration aa:
   - Initial speed v_0 = 5 m/s.
   - Final speed v_f = 0 m/s.

- Use the formula $a = (v_f - v_0)/t$ to calculate acceleration:

$a = (0 - 5)/0.1 = -50\ m/s^2$

3) Calculating impact force FF:
   - Mass m = 70 kg.
   - Acceleration $a = -50\ m/s^2$.
   - Use the formula $F = m \cdot a$ to calculate the impact force:

$F = 70 \cdot (-50) = -3500$ N

Explanation of simulation results

Through simulation analysis, it can be determined that the impact force experienced by the athlete during the collision is approximately −3500 N. The negative sign indicates that the direction of acceleration is opposite to the initial velocity, indicating a deceleration process. This result suggests that the floor needs to withstand an impact force of about 3500 N to ensure that it does not suffer significant damage or cause harm to the athlete during collisions.

3.4. Stress distribution analysis

Using FEA technology, we can meticulously analyze the stress distribution on damaged floors when they are subjected to impact forces [16]. This method allows us to simulate how different types of floor damage—such as cracks, breakages, or dents—affect the overall structural integrity of the flooring. Stress concentration points, which are often the most severely damaged areas, play a critical role in the dynamics of impact forces. These points can significantly increase the local stress levels, making it easier for athletes to experience greater forces when they contact these regions. By leveraging FEA **(Figure 2)**, we can pinpoint these critical areas and understand the detailed mechanics of how the damage propagates under various loading conditions. This detailed analysis is essential for developing improved flooring designs that can better distribute these stresses and reduce the risk of further damage and potential injuries to athletes. Such insights are invaluable for both preventive maintenance and the design of more resilient sports flooring systems.

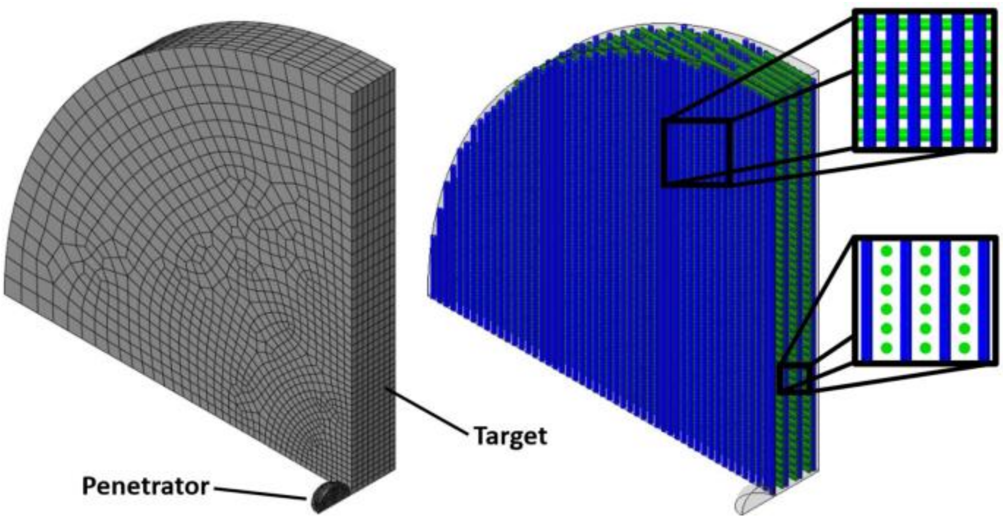

Figure 2. FEA analysis.

3.5. Damage prediction model

Based on the collision model of the athlete and the results of stress distribution analysis, we can establish a damage prediction model to foresee the types and severity of injuries athletes might sustain under different scenarios. Firstly, using FEA technology, we model the collision scenarios between athletes and floors during movement, considering various variables such as different intensities, angles, and speeds of movement. FEA is highly effective in simulating these dynamics, providing detailed insights into stress distribution across different parts of the athlete's body. By conducting simulation analysis, we obtain precise stress distribution data, which are then input into the damage prediction model. This model can evaluate potential injuries under various collision conditions based on the stress distribution [17]. For instance, during high-intensity activities, the model might predict possible fractures or soft tissue injuries, while during lower-intensity activities, it might predict minor sprains or bruises. This approach allows for a comprehensive assessment of injury risks athletes face under different conditions, thereby facilitating the development of more effective prevention and intervention measures to ensure athlete safety.

3.6. Field validation

3.6.1. Experiment setup

The research team established a test platform in the laboratory to simulate a damaged floor by embedding force plates into the designated damaged areas. A motion capture system, comprising multiple high-precision cameras, was employed to capture athletes' movements and trajectories in real-time.

3.6.2. Experimental steps

1) Preparation Phase:
    - Placement of Simulated Flooring: A sample of simulated damaged flooring was carefully placed on the force plate to replicate real-world conditions.
    - System Installation and Calibration: The motion capture system and force plate were installed and meticulously calibrated to ensure the accuracy and reliability of the data collected during the experiments.
2) Data Collection:
    - Standardized Movements: Several athletes were instructed to perform a series of standardized movements, including jumping, running, and sudden stopping. Each action was repeated multiple times to accumulate a comprehensive dataset.
    - Force Plate Measurements: The force plate recorded the vertical and horizontal impact forces exerted by the athletes upon contacting the floor. This data was crucial for understanding the forces involved during different movements.
    - Motion Capture Recording: The motion capture system continuously recorded the athletes' full-body movement trajectories, with a particular focus on landing points and postural adjustments during and after contact with the floor.

Figure 3. Kinematic analysis in dropping damage model.

3) Data Analysis:
    - The motion capture data was utilized to analyze the kinematic characteristics of the athletes' movements, such as speed, acceleration, and landing angles. This analysis provided insights into the dynamic behavior of athletes during various actions (**Figure 3**).
    - Impact Force and Stress Distribution: The force plate data was combined to calculate the maximum impact forces and stress distribution experienced by the athletes during each contact with the floor. This step was vital for assessing the mechanical impact of the movements on the simulated damaged flooring.
    - Athletic Response Analysis: The athletes' movement responses on the simulated damaged floor, including posture adjustments and force feedback, were analyzed to determine how the damage influenced their biomechanics and safety.

3.6.3. Experimental results

The experimental results indicate that different types of floor damage significantly impact the forces experienced by athletes and their movement responses. Specifically, when athletes encounter cracks in the flooring, the force plate records a substantial increase in vertical impact force peak values [1]. This suggests that the presence of cracks intensifies the impact forces transferred to the athlete upon contact, likely due to the irregular surface geometry which disrupts the uniform distribution of forces. The motion capture data further corroborates this finding by showing more intense posture adjustments at the moment of landing, indicating that athletes instinctively modify their stance to compensate for the unexpected surface irregularities. These adjustments may involve rapid changes in limb positioning and increased muscular effort to maintain balance and stability, potentially increasing the risk of injury.

In the case of fragmentation damage, where large areas of the flooring are broken into smaller pieces, the force plate data reveals an uneven distribution of impact forces. This unevenness is attributed to the fragmented surface, which creates varying levels of resistance and support, causing athletes to experience unpredictable forces during their movements. The motion capture system detects more lateral and shifting movements in these scenarios, reflecting athletes' attempts to regain balance and control when landing on an unstable surface. These movements are characterized by increased side-to-side motion and a higher incidence of weight shifts, suggesting that athletes are more likely to lose balance and potentially suffer falls or other injuries due to the compromised stability of the flooring [18].

These findings highlight the critical importance of maintaining flooring integrity in sports facilities. By understanding how different types of floor damage affect athletic performance and safety, facility managers can prioritize repair and maintenance efforts to mitigate these risks. Ensuring a consistent and stable playing surface is essential for protecting athletes from injury and enhancing their overall performance.

3.6.4. Model validation

Comparing the experimental data with the simulation results of the damage prediction model, we can validate the model's accuracy. For instance, if the prediction model is accurate, the calculated impact forces and stress distributions in the model should match the force plate data, and the kinematic characteristics should align with the motion capture data. Ultimately, this data helps researchers optimize and improve the prediction model, enhancing its reliability and accuracy in practical applications.

3.7. Risk assessment

Risk assessment of damaged sports flooring is critical as it significantly increases the risk of athlete injuries. Damaged flooring, such as surfaces with cracks, uneven areas, or delamination, poses substantial threats to athletes' safety. Regular on-site inspections are essential to assess these specific threats. These inspections involve detailed visual assessments and the use of specialized tools to measure surface irregularities and material degradation. Additionally, collecting and analyzing data on athlete injuries linked to these flooring conditions helps in understanding the correlation between floor damage and injury incidence [19]. By systematically gathering this information, facility managers can identify high-risk areas, prioritize repair efforts, and implement preventive measures to maintain a safe sporting environment. This proactive approach ensures that the risks associated with damaged sports flooring are minimized, thereby protecting athletes' health and enhancing the overall safety of sports facilities [20,21].

4. Preventive measures for sports flooring safety risks

4.1. Material selection

In terms of material selection for sports flooring, it is essential to choose materials with a high elastic modulus, such as polyurethane and rubber, which can effectively absorb impact forces and thereby reduce the injuries athletes may sustain during sports activities. These materials are known for their excellent shock absorption properties, making them ideal for high-impact sports environments. Additionally, using materials with superior fatigue resistance is crucial to ensure that the flooring does not quickly age and fail under long-term, high-frequency use. Materials like polyurethane exhibit outstanding fatigue resistance, enhancing the longevity of the flooring. Furthermore, selecting materials with anti-slip surface treatments that provide an appropriate coefficient of friction is vital for reducing the risk of athletes slipping. By carefully choosing these materials, the safety and performance of sports flooring can be significantly improved, providing a safer environment for athletes.

However, the environmental implications of using advanced materials like polyurethane and rubber should also be considered, especially concerning their lifecycle and recyclability. Including a lifecycle assessment (LCA) for the materials proposed is crucial to address their environmental impacts from production to disposal. This assessment can help in understanding and mitigating the potential environmental costs associated with these materials, ensuring a more sustainable approach to sports flooring design and material selection [22]. By integrating LCA into the material selection process, we can make more informed decisions that balance performance, safety, and environmental responsibility. Regular maintenance and upkeep, including periodic inspections and timely repairs of any cracks, dents, or surface wear, are also crucial to maintaining the flooring's integrity and performance. Proactive maintenance strategies significantly lower the risk of damage, ensuring a safe and reliable surface for athletic activities [23].

4.2. Design optimization

Adopting a multi-layer composite structure in flooring design can effectively enhance material performance and longevity. The top layer is engineered to provide comfort and anti-slip properties, ensuring athletes maintain traction and stability during their activities [24]. Incorporating materials such as polyurethane in the top layer can significantly improve surface grip and comfort. The middle layer offers essential elasticity and shock absorption, crucial for minimizing impact forces that athletes experience. Materials like EVA (ethylene-vinyl acetate) are effective in absorbing shocks and reducing the stress transmitted to athletes' joints. The bottom layer provides foundational support and durability, utilizing materials such as high-density polyethylene, which are known for their robust structural properties [25].

By optimizing the structure of the flooring, impact forces can be uniformly distributed, preventing excessive damage in stress concentration areas and thus enhancing the flooring's overall durability and safety. To meet the diverse needs of various sports, different types of flooring should be tailored according to the specific intensity and frequency requirements. This approach not only ensures the best sports experience but also significantly contributes to safety assurance, as highlighted in various studies within the field of sports science and materials engineering.

However, high-performance materials and designs recommended for sports flooring may have significant cost implications. It is essential to investigate cost-effective alternatives that still meet safety standards. For instance, researching less expensive materials with adequate performance characteristics could provide viable solutions for smaller or less-funded sports facilities. Additionally, proposing funding models or subsidies can help underfunded sports facilities afford the recommended flooring materials and maintenance practices. By addressing these economic challenges, it becomes possible to achieve a balance between performance, safety, and affordability in sports flooring design.

4.3. Routine maintenance

Regular inspections and maintenance of the flooring's surface and structure, as well as timely repairs of any cracks, breakages, and dents, are essential for maintaining the flooring in optimal condition. Routine checks are important to identify and address potential issues before they escalate. Additionally, keeping the flooring clean and preventing the accumulation of dust and debris are crucial practices. Using appropriate protective agents for surface treatment can significantly enhance the durability of the flooring by forming a protective barrier against wear and tear. Furthermore, controlling the temperature and humidity environment in the venue is vital to prevent the flooring from expanding, contracting, or deforming due to climatic changes [26]. These measures collectively ensure the long-term performance of sports flooring and the safety of athletes.

4.4. Experiments and tests

Conducting impact tests on the flooring in a laboratory environment is essential to evaluate its shock absorption effect and impact resistance. These tests simulate real-world conditions to determine how well the flooring can mitigate impact forces, ensuring athlete safety. Such tests are crucial for identifying materials that offer optimal protection against high-impact activities. According to the EN 14904: A4 standard, the performance parameters for sports flooring include:

- Shock Absorption: ≥ 55% and < 75%, with a result of 63%
- Vertical Deformation: ≥ 2.3 mm and < 5.0 mm, with a result of 2.3 mm
- Ball Rebound: ≥ 90%, with a result of 95%
- Friction: ≥ 80 and ≤ 110, with a result of ~ 85
- Rolling Load: ≥ 1500 N, with a result of 3500 N
- Point Load: None specified, with a result of 6000 N (~ 600 kg)

These parameters highlight the flooring's ability to absorb impact, provide sufficient deformation, and maintain consistent performance under stress. Fatigue tests involving repeated loading are also conducted to assess the fatigue life of flooring materials. These tests help ensure the flooring's stability and durability in long-term use by simulating the wear and tear that occurs over time. Testing on Junckers flooring included using a solid rubber wheel with a width of 50 mm and a diameter of 100 mm for rolling load tests, and a point load test of 100 × 100 mm, resulting in a load capacity of 6000 N (~ 600 kg).

Collectively, these laboratory tests ensure the performance and safety of sports flooring. Through scientific material selection, optimized design, and rigorous routine maintenance, the safety of sports flooring can be significantly improved, thereby reducing the risk of athlete injuries during sports activities.

5. Conclusion

In this analysis, we explored key factors affecting sports flooring performance and safety, including the impact of damage, material selection, and maintenance. We discussed how different types of floor damage, such as cracks, breakages, and dents, affect the structural integrity and safety of the flooring, and how using FEA for stress distribution modeling can help predict potential injuries. High elastic modulus materials like polyurethane and rubber, along with multi-layer composite structures, were highlighted for their effectiveness in enhancing flooring durability and safety. Regular inspections, maintenance, and laboratory tests, including impact, friction, and fatigue tests, are essential for assessing and maintaining flooring performance. Additionally, understanding the effects of environmental conditions, such as humidity and temperature fluctuations, on flooring materials is crucial for preventing structural damage.

By implementing these comprehensive measures, which include scientific material selection, optimized design, and rigorous routine maintenance, the safety and performance of sports flooring can be significantly improved. This holistic approach reduces injury risks, ensures the longevity of the flooring, and enhances the overall athletic experience. These findings connect back to our initial thesis, demonstrating how advancements in sports flooring materials and design can enhance athlete safety and performance. The broader implications of this research suggest that continued innovation in this field will not only provide safer and more effective flooring solutions but also inspire further studies and practical applications in various sports disciplines.

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Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Hezhou University (protocol code 15/HU/0088 and 12/2024 of approval).

Conflict of interest: The authors declare no conflict of interest.

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