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Superiority of Composite Baseball Bats: Trampoline Effect, Acoustics, Compliance and Safety

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Abstract: The superiority of composite (blended/multiple materials) baseball bats over wood bats, bolstering 10-15% higher exit velocity is attributed to the trampoline effect (bounciness) resulting from advanced materials, deliberate breaking, reduced sting vibrations, balanced weight, and an expanded sweet spot. This article systematically examines (**B7**: **B**olstering (enhanced), **B**lended (composite) **B**aseball **B**ats with **B**ounciness, **B**ang (sound), and **B**anishment (safety), focusing on the comparative superiority of composite bats over wood bats for 12U players, where they are permitted. In a controlled environment (70 ^{o}F), the average exit velocity of a ball on the composite bat are >10% superior to those of a wood bat when hitting balls off the tee, while >15% superior when hitting balls pitched at a speed of 50 MPH. Experimentally, metal bats produced a louder (102 to 106 dB), high-pitched *"bang"* due to their hollow structure, while composite and wood bats emitted a quieter (91 to 95 dB), low-pitched sound, when measured close to the batter. The variation in decibels was influenced by ball speed, impact point, and bat design, affecting player perception. Composite bats gain power over time as they break in, enhancing performance but also introducing inconsistency and potentially increasing injury risk. Authors shed light on the importance of baseball safety gear for players on the diamond, helping them avoid possible injuries.

Keywords: Exit velocity, acoustics (sound), safety, trampoline effect, composite materials, efficiency

I. Introduction

Baseball and softball engage approximately 60 million people worldwide across 140 countries in Asia, the Caribbean, and the Americas. Baseball (Sherwood, 2015) gained popularity in the United States during the 19th century, becoming a global phenomenon that transcends cultures and generations. Unlike many sports, baseball has a flexible time limit, instead each game has 9 innings adding a unique layer of suspense and competitiveness to the game. Fans analyze and predict outcomes based on player performance and team dynamics, fostering lifelong fandom, friendship, and family ties. This research focuses on baseball bat design and performance, particularly the evolution of composite bats. Composite bats, fabricated from materials like carbon fiber, plastics, and Kevlar, offer enhanced flexibility, and strength. We explore factors such as break-in procedures, stiffness, and material properties, shedding light on the fascinating world of baseball equipment.

Over the past two centuries, baseball (Drane, 2008) has undergone numerous amendments to its playing techniques and equipment. The baseball bat stands as the most central element of the game. Composite bat manufacturers usually recommend using composite bats in temperatures of 50-60 degrees Fahrenheit. In colder temperatures, composite bats have a tendency to crack or break more easily due to the contraction of fibers in the composite material. Major League Baseball prohibits the use of Composite and Alloy (aluminum) bats due to performance advantages, safety concerns, and the tradition of using wood bats. Major, minor, and Little League baseball have distinct guidelines regarding field dimensions, equipment usage, and bat performance, captivating players, umpires, and spectators alike. While Little League players can choose between wood, alloy/metal, or composite bats, minor and major league players are constrained to wood bats for safety reasons, negating any unfair advantage. The first baseball convention was organized in 1857, and the standard for baseball bats was introduced with the manufacturing of wood bats in 1875.

Composite baseball bats (Sherwood, 2008), as the name suggests, are fabricated by combining carbon fiber, plastics, rubber, fiberglass, Kevlar, graphite, and other specialty elements. Precisely woven or braided strips form the bat's handle and barrel, followed by high-pressure, high-temperature treatment in an oven for hardening and shaping. The bats are then painted to enhance their appeal. Before reaching the market, composite bats undergo rigorous quality assurance, including weight, flexibility, safety, defect, and drop tests. Compared to conventional wood or aluminum bats, composite bats offer superior field performance (Sherwood, 2008). More advanced composite materials found in bats tends to enhance performance using nano-composites, leading to enhanced strength, sustainability and durability. These enhanced performances of bats and safety avoiding the unfair advantages to other players with fair play.

Wooden baseball bats (Drane, 2016), made from mainly birch, maple, or ash trees, are crafted using computer numeric control (CNC) machines. The process involves carving billets to specific dimensions and weights, followed by sanding, painting, and inspection for defects or grain patterns. Metal baseball bats (Shinataro, 2004), crafted from high-grade aluminum or alloy, undergo shaping and forging using CNC programs. They are then heat-treated in a sodium nitrate bath, followed by quenching in

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water before painting and quality testing. Typically, wooden bats are inexpensive, while metal bats provide durability. Composite bats, although a bit more expensive, offer an excellent sweet spot despite being less durable.

Nathan *et al.* conducted a relative study of the performance of five aluminum baseball (Nathan, 2011) bats using field data, high-speed laboratory testing, and modal analysis. An experimental investigation explored the relationship between baseball bat performance, moment of inertia (MOI), and barrel stiffness (Broe, 2010) for both aluminum and composite bats; accounting for bat properties and shed light on the factors influencing performance. Broe *et al.* experimentally investigated the maximum performance of composite bats and tracked changes in their performance over their useful life. The study focused on accelerated break-in procedures, barrel stiffness (Broe, 2010), first hoop frequency (vibrational modes), and the ball-bat coefficient of restitution (BBCOR) in the field environment, analyzing six composite baseball bats with negligible performance differences. An analysis of wood baseball bat durability with bat profile and slope of grain employing finite element modeling (Blake, 2022) is reported. Account of maple and ash material bat properties dependence on wood density (Fortin Smith, 2018) for bat/ball impact modeling is presented.

Composite baseball bats, boasting >10% faster exit velocity compared to wood bats, owe their superiority to advancements in composite materials. These materials reduce sting vibrations, enlarge the sweet spot, enhance trampoline (rebound), and maintain balanced weight. Over 250 hits ensure careful breaking-in for 12U batters during well-hit balls off the tee and 50MPH by pitching machine. In experimental testing, metal bats produce a high-pitched, louder sound (102 to 106 dB) due to their hollow structure, while composite bats emit a quieter, low-pitched sound (91 to 95 dB). The decibel variation results from ball speed, impact point, and bat design, influencing player perception. Although composite bats gain power over time as they break in, this enhancement may increase injury risk. Nevertheless, this study and manuscript focus on highlighting the advantages of composite bats for 12U players where their use is permitted.

Experimental section:

We compare the performance measures of various baseball bats. Two key metrics are commonly used: collision efficiency and the BBCOR. Collision efficiency assesses how effectively a bat transfers energy to the ball upon impact, considering bat speed, ball speed, and the collision angle. On the other hand, BBCOR measures the elasticity of the collision between the ball and bat, as well as the rebound speed of the ball relative to its incoming speed.

Our former selection and performance rationale of wood vs. aluminum baseball bats experiments (Pol, 2024) , we revealed that metal baseball bats exhibit approximately 3% enhanced exit ball velocity compared to wood bats of analogous size, diameter, and weight. Exit velocity is the speed of the baseball after it contacts the bat and travels through the air. The higher the bat speed, the greater the chance of achieving a higher exit velocity, and vice versa. A Junior Hack Attack pitching machine, a standard model, was used to set the ball velocity, 50MPH.

In our current experiments, we employed specialized equipment, including sound level meters and an iPhone 15 ProMax Decibel Application, in a controlled testing environment. These tools allowed us to capture peak sound levels produced by metal and composite bats during impact with a baseball close to the batter. The speed radar, purchased from Bushnell, has an accuracy of ±1 MPH. To calibrate the velocity gun, we matched its readings to the pitching machine's set speed with a 1 MPH precision. We obtained a bucket of standard leather-covered baseballs from Wilson. For the tee tests, we employed a standard batting tee produced by Tanners Tees. Additionally, we conducted our experiments at LifeLong Sports, an indoor baseball and softball facility located in Lafayette, Indiana, USA.

The science behind baseball bat exit velocity enhances our understanding of the game and contributes to its continuous evolution. The exit velocity of a baseball is influenced by the bat speed, pitch speed, and bat material. Faster bat and pitch speeds result in greater exit velocity. The well-known equation calculates the bat speed to exit velocity. $Ve=MF*(PS)+(1+MF)*BSVe=MF*(PS)+(1+MF)*BS$

Where, Ve is the exit velocity (MPH), MF is the material factor (= 0.2 for wooden bats), PS is the pitch speed (MPH), BS is the bat speed (MPH).

II. Result and discussion

Trampoline effect (Bounciness**):** The impact/collision/bounciness (Walker, 2010) between bat-ball is called as the Bat-Ball Coefficient of Restitution (BBCOR, or lost energy) as the ball travels farther with more energy. During the bat-ball collision they compress each other, the amount of stored energy returned to ball referred as Trampoline Effect. Because of inherent material properties, wood bat *(Fig. 1a)* barely compresses compared to composite *(Fig. 1b)* or aluminum *(Fig. 1c)* bats. Upon the ball-wood bat collision, the baseball compresses >50% of its original size losing >70% of its internal energy and portion is dissipated in the bat's vibrational modes. However, in composite or aluminum bats, they are designed and constructed to generate a larger trampoline effect (Walker, 2010) allowing minimum ball deformation retaining internal stored energy to the ball upon contact with increased exit velocity *(Fig. 1d,e)*. As collision between ball-bat is directly impacted with their composition therefore in MLB (MLB, 2012) the cork-rubber-yarn stitching to spherical shape, ~5 ounces weight, and 9 inches circumference is regulated keeping play fair.

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Figure 1. The bats used for experimental data collection; a) wood, b) composite, c) metal bats with their plausible interfaces with the baseball, d) Artificial intelligence (AI) generated drawing depicting the trampoline effect upon bat-ball collision, e) employed speed gun (insert shows measured speed), f) AI generated drawing demonstrating the acoustic effect using Copilot and g) screen shot of a decibel meter reading with iPhone Prox max 15.

The temperature effect (Drane, 2013) on the ball-bat collision studied by Drane and Sherwood, concluding that in a cold environment rebound speed 3% lower than standard COR, while higher showed 1% at elevated temperature. The *"sweet spot"* of a baseball bat is typically found between both bending and hoop modes (Russel) on the bat barrel, yielding a greater baseball exit velocity (BEV) on a hollow bat of metal or composite. The hollow barrel wall compresses as a substitute of the ball performs like a spring giving more *'pop'* to the ball enhancing exit velocity with unfair advantage to the player. Varieties of baseball bats in the market with a performance and the safety matrix are available. The metal and composite bat materials generate *"hoop and bending"* modes inferred as trampoline effect, while wood only generate bending modes with longitudinal axis flexibility (Crisco, 2002). The selection and quality of material directly affect ball exit velocities by the trampoline effect typically exhibited in metal/composite bats, sometime causing life threatening injuries to youth players. During the break-in period of composite bats, the structural changes are expected, which might affect the way it hits the ball, players shall be vigilant to follow manufacturer guidelines. The trampoline effect in composite baseballs plays a crucial role in the game, affecting *hitting dynamics* and overall performance.

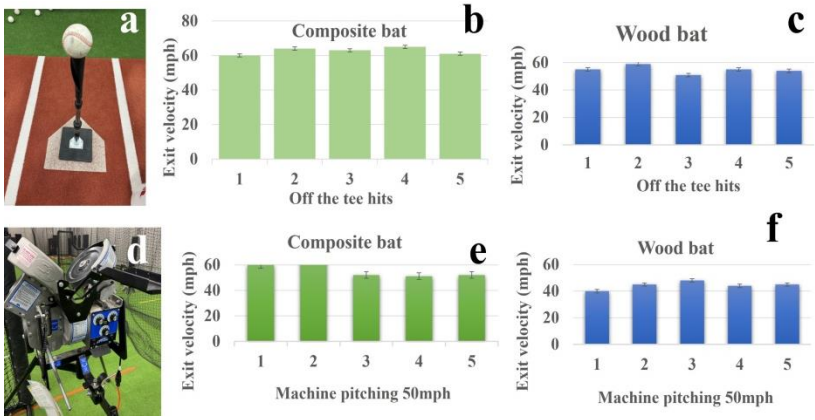

Figure 2. Photo of a) off the tee, b) exit velocity for composite bat, c) exit velocity for wood bat; d) photo of pitching machine set at 50mph, e) measured exit velocity for composite bat, and f) exit velocity for wood bat.

Acoustic (Bang) of baseball bats: Metal bats have a resonant, ringing quality produces high-pitched, intense "ping" sound at a higher decibel level, while composite or wood bats have a more muted, dampened sound due to the materials' different acoustic properties and associated vibrations upon an impact with the ball.[12] Typically, metal bats produce sharper sound at certain frequencies due to hollow metal structure, while composite bats yield wide noise distribution *(Fig. 1f,g)* affecting player's perception.

The exit velocity data for 5 balls hit off the tee *(Fig. 2a)* using composite *(Fig. 2b)* and wood *(Fig. 2c)* bats are illustrated. The highest exit velocity achieved with the composite bat falls within the range of 60-64 MPH, while the wood bat consistently reaches 51-59 MPH. The average exit velocity for composite bat is >10% superior to the wood bat when hitting balls off the tee. In *Fig 2d*, five balls were pitched at a speed of 50 MPH using an arm-type pitching machine and exit velocity data was collected for both composite and wood bats. The highest exit velocity achieved with the composite bat *(Fig. 2e)* ranged from 51 to 60 MPH, while the wood bat (Fig. 2f) consistently reached speeds of 40 to 48 MPH. The higher average exit velocity data for composite bat demonstrate >15% superior when hitting balls those were pitched at a speed of 50 MPH.

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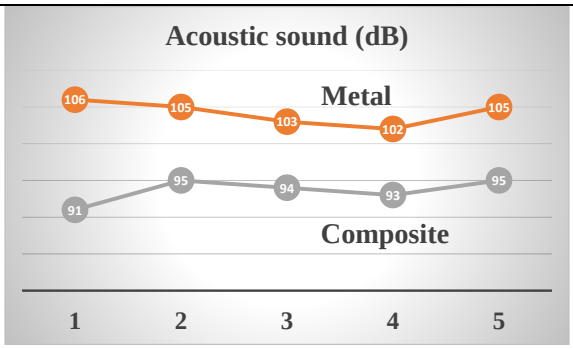

Figure 3. Chart demonstrates measured decibel sound frequencies for composite and metal bats for off the tee ball hits.

In our experimental work, between 102 to 106 dB decibel (dB) of sound was measured for a metal bat, while 91 to 95 dB was measured for a composite baseball bat in a controlled environment *(Fig. 3)*. The measured dB deviation is a result of bat material, pitch speed, impact point, and the bat's design. It is noted that highest dB with loud 'ping' sound is measured when the ball impacts on the "sweet spot". The difference remains consistent when the dB sound measured as a function of distance from the batter. Composite/wooden bats tend to produce a relatively smooth frequency analogous to composite bats.

For context, city traffic or a noisy bar/restaurant could be 85 dB loud, therefore only prolonged exposure to noise above 85 dB pose a risk to hearing damage. Please note that composite bats are quieter, however, still loud enough to be clearly heard on the field. The sound of the bat is an integral part of batter's psychological and cognitive (Frontiers, 2020) aspect as it provides immediate feedback to the batter about the swing mechanics/quality of their hit affecting batter's timing and decision-making in real games. The auditory feedback (Tethys, 2021) from the bat is crucial affecting audience and coaches depicting player's swing mechanics, confidence, and hitting approach resulting in an enhanced performance. It's important for players to use league or association approved bats for baseball play ensuring the safety of all the participants. The softer sound could mislead that the ball is not hit as hard, however players, umpires and spectators should always be attentive, as batted balls can still travel at high speeds. Understanding bat acoustics contributes to player experience and overall performance.

Compliance (Banishment) on the composite baseball bats: Composite baseball (Smash It Sports, 2024) bats offer a larger sweet spot and reduced weight, leading to greater hitting distances. Ultimately, the decision to lift the ban on composite bats would need to consider the balance between performance enhancement, safety, cost, tradition, and fair play. Such complex decision involves input from players, coaches, equipment manufacturers, and regulatory organizations. The complex topic of banning composite baseball bats involves various scientific principles and testing methods. The report by UMass Lowell details the comprehensive laboratory (Baseball Hover, 2023) test methods used to measure the performance of nonwood bats and the setting of performance limits to maintain the balance between offense and defense in the sport. A broader understanding of the scientific principles behind the performance of different bat materials (wood to metal and composite) (Baseball Bible, 2023) and the revolutionary advancements in design and performance of baseball bats is accomplished. The rules (19th Century Baseball) on bats utilization are designed to maintain the integrity of the game and provide a level playing field for all participants.

Apart from several advantages of composite baseball bats (Walker, 2010) comes with certain disadvantages, including: i) break-in period, hitting several hundred balls to optimize the bat's flexibility and responsiveness, ii) durability concerns due to used polymer degradation in cold atmosphere, iii) susceptible to cracking or damage upon exposure to extreme temperatures or improper use, iv) higher cost because of involved advanced materials and manufacturing processes, v) a potential for the delamination of composite layers, affecting the bat's longevity and vi) providing minimum time to react to a batted ball being dangerous for pitchers and infielders increasing the risk of injury disturbing the integrity of the game.

Often, composite baseball bats are prohibited in most of the leagues and games as they provide an unfair advantage to the hitters due to *"trampoline"* effect with enhanced exit ball velocity compared to the wooden bats. Safety standards, game guidelines and certifications, such as BBCOR (Batted Ball Coefficient of Restitution), shall be in place to ensure that non-wood bats perform similarly to wood bats and do not pose additional risks. Due to performance alteration with more ball hits composite known to become powerful significantly increasing ball's exit speed thus major leagues and associations have banned the use of composite bats for safety and unfair advantage reasons. Composite bats tend to be more expensive than aluminum or wood bats since they utilize advanced materials. Though the composite bats are designed to be durable due to synergistic effect of several materials, they are prone to crack or break upon repeated impact, hence regular visual inspection for damage is important ensuring that the bat is safe to use. Moreover, composite bats are sensitive to cold weather, enhancing the risk of cracking thus it is recommended to use them as per manufacturers guidelines. Recently, banned and allowed bats for perfect game tournaments (Better Baseball, 2024) are accounted. Understanding bat compliance and legality ensures game integrity and safety.

Safety: Baseball safety equipment plays a crucial role in ensuring the well-being of players during the game. The high-quality leather *baseball gloves* are essential safety baseball gears for effective fielding ground balls, catching pop flies, and making

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game-saving plays dramatically minimizing the risk of hand injuries, especially for fielders and catchers. A baseball *helmet* is the most essential piece of equipment, while practicing or playing. Quality branded helmets are designed to protect player from high speed pitched balls and foul hits to catchers assuring safety and comfort.

Baseball cleats are very crucial for players on the diamond providing grip, allowing to sprint, pivot, and make agile moves with confidence while running the bases or chasing down a fly ball. Baseball cleats, comes in four main types; metal, molded, turf and interchangeable with its material dependent surface traction and performance benefits. The *right cleats* ensure optimal performance and minimizes injury risks, must be selected based on playing style, league rules, and field conditions. Leg guards provides protection, especially when facing hard-hitting pitchers. The anatomical design of baseball shin guards includes a durable outer shell, foam or gel padding for cushioning, adjustable straps for a snug fit, and knee protection for catchers

Baseball *catchers* wear a combination of protective gear to ensure safety to focus on their game with confidence. Catcher's mitt is specialized glove for catching pitches, mask/helmet protects the head and face avoids possible head injuries from wild pitches, foul tips, or bat swings, chest protector shields the chest and abdomen preventing injuries from pitches, foul balls, and collisions at home plate, leg/shin guards cover the legs from knees to ankles guards against foul tips and sliding runners, throat guard protects throat area, mouth guard protects teeth and jaw. The protective cup for male players ensures groin safety. Batters can opt for elbow guards, shin guards, and hand guards. Proper warm-up activities reduce the risk of strains and sprains, teaching players correct throwing, hitting, and fielding techniques enhancing safety and most importantly maintaining physical fitness helps prevent injuries, making baseball a safe and thrilling game. Baseball *sliding mitts* are specialized caring gear aimed to protect a player's hand and fingers from fielders landing on them, or jamming fingers. Durable material padding reduces the risk of damages, allowing players to slide with confidence. Ensuring player safety is paramount, and investing in quality protective equipment is truly essential. The limitation and broader impact of this manuscript B7 (Bolstering Blended Baseball Bats with Bounciness, Bang, and Banishment) study highlights significant performance differences between composite and wooden baseball bats, with composite bats offering advantages such as larger sweet spots, reduced vibration, and higher exit velocities. However, these benefits come with potential drawbacks, including safety concerns, regulatory challenges, and impacts on skill development, necessitating a balanced approach to equipment regulation in baseball to maintain fair play and ensure player safety across all levels of the sport.

III. Conclusions

This article methodically describes B7 (Bolstering Blended Baseball Bats with Bounciness, Bang, and Banishment). The superiority of composite baseball bats over wooden bats, resulting in 10-15% higher exit velocity, is attributed to advanced composite bat materials, careful breaking, reduced sting vibrations, balanced bat weight, and a wider sweet spot. In a controlled environment using a batting cage and pitching machine, 12U players show that the average exit velocity of a ball on the composite bat are >10% superior to those of a wood bat when hitting balls off the tee, while >15% superior when hitting balls pitched at a speed of 50 MPH. Experimentally, metal bats produce a louder, high-pitched sound (102 to 106 dB) due to their hollow metal structure. In contrast, composite bats emit a quieter, low-pitched sound (91 to 95 dB). The variation in decibels results from factors such as ball speed, impact point, and bat design, affecting players' perception. Composite bats gain power over time as they break in, enhancing performance potentially raises the risk of injury, making them inconsistent and non-compliance therefore only allowed in little leagues. Baseball safety gears are essential for both physical well-being and mental reassurance on the diamond baseball field.

Acknowledgment

A baseball enthusiast, SVP formulated a scientific hypothesis for the presented research work. Acting as a 12U baseball player, SVP generated exit velocity and decibel data. Family members and friends assisted in measuring the exit velocity and decibel readings. Microsoft Copilot (GPT-4) was employed to draw trampoline effect and acoustics figures as well as gather information on former research and development activities in the baseball field. VGP plotted the results, analyzed, and methodically articulated obtained data to materialize scientific article. Finally, Ithenticate software was used to conduct plagiarism check on the final manuscript. The authors are thankful to LifeLong Sports, an indoor baseball and softball facility located in Lafayette, Indiana, for providing exceptional training resources and support throughout our journey. Their commitment to fostering athletic development has greatly contributed to our success.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Data availability statement

The presented data that support the findings of this study are available with authors in their computers, will be provided upon request.

Declaration of funding

No funds were available for this project.

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