An Experimental Investigation of the Effect of Use on the Performance of Composite Baseball Bats

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TOPICS: Composites, baseball, bats

Abstract: The choice of materials used to make baseball bats has evolved over the years from traditional solid wood to aluminium and now to composites. To determine whether or not a bat's design is in compliance with the batted-ball performance standard for a given league, a new bat is tested in a hitting machine where the bat is subjected to a limited number of hits. Considering the material behaviour that occurs within a composite material subjected to numerous impacts, the batted-ball performance of composite bats can theoretically improve with use as the polymer-matrix develops microcracks. These microcracks can soften the barrel of the bat which may allow the trampoline effect to increase. As the trampoline effect increases, there is potential for the batted-ball speed to increase. This paper will discuss the observed evolution of the performance for six currently popular composite baseball bats that were subjected to cycles of performance testing followed by repeated use in a controlled laboratory setting. None of the six composite baseball bats exhibited a significant change in performance. Some of the composite bats did exhibit poor durability.

Key words: Composites, baseball, bats, performance, durability.

1- Introduction

The construction of baseball bats used at the amateur level of play has evolved over the past 40 years from traditional solid wood to aluminium and to combinations of materials, i.e. composites. As the choice of materials has evolved so has the potential hitting power of the bats. To allow these bats to be used without compromising the balance between offense and defence, governing bodies have come to depend on comprehensive laboratory test methods to measure the batted-ball performance of these nonwood bats and to use these same test methods to help in the setting of performance limits.

It is commonly accepted from a material-science perspective that with each bat/ball impact the microstructure of the bat material can be altered. Wood bats can flake, i.e. delamination of the wood rings, and crack. In aluminium bats, the material changes can be in the form of microcracking and denting. The microcracking can lead to a softening of the barrel, which in turn can lead to a change in the trampoline effect and a resulting change in batted-ball speed. The denting is a result of plastic deformation, which in turn can work harden the material and increase the strain energy that can be stored in the bat and subsequently returned to the ball.

In the last five years, bat manufacturers have been implementing fabric-reinforced composite materials into their designs. Composite materials admit the option for a variety of matrix and reinforcement materials and allow the designer to tailor the material properties along the barrel and handle of the bat, thereby being able to tune the bat designs to span a range of barrel and handle stiffnesses that could never be achieved with aluminium. An additional design parameter is how the material behaviour can change with use. This last design parameter is one that is cause for concern and the motivation for the current study to investigate how the performance of a composite baseball bat can change with use.

2- Background

The test methodologies used by the various governing bodies for amateur baseball all quantify bat performance using new bats tested in a hitting machine. The number of hits in these tests can range from as few as six at one location on the barrel of the bat to as many as 60 over a 5.08-cm (2-in.) span along the barrel. At the conclusion of the test, the bat design is determined either to comply or not comply with the respective governing body's performance limit. The procedure for certifying whether or not a new bat model is compliant with the performance standards of the respective governing body is to simulate a bat/ball collision in a controlled lab environment. The testing is conducted on a new bat, i.e. a virgin specimen. Depending on the chosen performance metric and its associated limit, the bat is concluded to be either compliant or noncompliant with the performance standard. For example, the NCAA uses a BESR (Ball Exit Speed Ratio) as its metric for performance, and Little League uses BPF (Bat Performance Factor) as its metric for performance.

Drane and Sherwood (2002) found that the performance of aluminium bats can change with use. They subjected bats to hundreds of hits using a hitting machine in the lab and players in the field and took batted-ball performance measurements periodically throughout the study. The data concluded that one bat showed an increase in performance while another bat showed a decrease in performance with use. While the data did not support a trend for a change in performance up or down, the data did support that aluminium-baseball-bat performance can change with use.

In the last decade, many composite bat designs have been introduced in amateur baseball and softball. Because these bats are relatively new to the game, there are limited quantitative lab data and qualitative field performance observations for this class of bats in comparison to wood and aluminium bats. However, one outstanding data point is a qualitative observation of a composite softball bat. It was discovered by softball players that this bat design exhibited batted-ball performance that increased with use. As a result, players would subject the bat to an accelerated "break in" by subjecting the bats to extreme impact conditions, e.g. hitting the bat against a tree, before using the bat in a game. This bat design tilted the balance of the game to the advantage of the offense. The Amateur Softball Association (ASA) was concerned that such bat performance could compromise the integrity of the game. In response to this concern, the ASA changed its certification test methodology from BPF (Bat Performance Factor) as described in ASTM Standard F1881 (2004) to using BBS (Batted-Ball Speed) similar to the test as described in ASTM F2219 (2007). The current ASA bat performance standard requires a softball bat to perform at or below the ASA BBS limit for the useful life of the bat. Thus, the laboratory certification test subjects the bats to virtually hundreds of hits by using a barrel rolling process and then subsequent performance testing in a hitting machine to quantify if and how the BBS changes with use.

To date, there are no known qualitative or quantitative data showing that any of the composite baseball bats currently being used at the high school and college levels are showing increasing or decreasing batted-ball speeds with use. The objective of the current study was to test a sample of current composite baseball bats and subject them to repeated baseball impacts using laboratory hitting machines to simulate the "life" of a composite baseball bat and examine if and how the batted-ball performance evolves with use.

3- Methodology

A total of six high-performance composite bats and one aluminium bat were tested in the current study. The aluminium bat was included as a reference point. All of the bats were 86.4-cm (34-in.) long and weighed approximately 879 g (31 oz.). The bats selected for the study had previously been certified to be in compliance with the NCAA BESR bat performance standard and were found to perform very close to the upper bound for the NCAA BESR. The bat performance was measured using a hitting machine, and the bats were subjected to accelerated hitting using a durability machine that can be programmed to scatter hits along the length of the barrel for a range of prescribed hit locations and speeds. The durability machine can shoot baseballs at the rate of one ball every 5 s at relative bat/ball speeds between 26.8 and 80.5 m/s (60 and 180 mph). These speeds correspond to the bunting of a knuckle ball (essentially zero bat swing at a slow pitch) and to the tip of a fast swinging bat hitting a fastball (relatively fast swing at a very fast moving baseball), respectively. Thus, the durability machine can span the range of bat/ball collisions that can occur on the field.

The batted-ball potentials of the bats were measured using the test protocol described in the NCAA Standard for Testing Baseball Bat Performance (2006). In the current study, there were two deviations from the NCAA protocol. The test was not stopped if a bat was found to exceed the upper limit for performance, and the performance test examined five locations along the length of the barrel regardless whether or not the sweet spot could or could not be isolated within the five hit locations. The five locations were 12.7, 14.0, 15.2, 16.5, and 17.8 cm (5.0, 5.5, 6.0, 6.5 and 7.0 in.) from the tip of the barrel. All valid and invalid hits were counted in the total hits on a bat. After the initial performance measurement of N hits, each bat was then subjected to 100-N additional hits in the durability machine to get a total of 100 hits on each bat. The hits in the durability machine were scattered over the same 12.7 to 17.8 cm (5.0 to 7.0 in.) locations from the tip of the barrel. The relative bat/ball speeds in the durability machine were between 58.1 and 62.6 m/s (130 and 140 mph). Each bat was then retested in the hitting machine to measure its performance followed by another 100-N hits in the durability machine, and so on.

The cycle of performance testing followed by hits in the durability machine were continued until the bat cracked enough such that the cracks would be obvious to a player or umpire and the bat would be deemed unacceptable for use in a game. Conditions for the stopping the test included:

- Crack that could be seen without the need of close inspection
- Crack that was rough/raised to the touch
- Protruding composite fibers
- Separation of barrel from the handle

4- Results

All of the bats cracked in the barrel with the exception of one of the composite bats, C1, which broke in the handle after being subjected to over 1000 total hits. Two of the six composite bats (C3 and C4) broke before the second performance cycle was completed, and thus, there are no performance data on those bats beyond that measured on the "new" bat. One composite bat (C2) broke during the initial performance test, so there are no data for that bat. Figure 1 is a photograph of Bat ID C2, which had the barrel completely separate from the handle during the performance testing. With 50% of these "high-performance" composite bats failing due to cracking with less than 100 hits, there appears to be a serious durability problem for some of the composite baseball bat designs.

Figure 1: Complete separation of handle and barrel for Bat ID C2

Of the three composite bats that have multiple complete-performance tests (C1, C5 and C6), the largest change in performance for a bat from one test to another was the drop of 0.012 in BESR at the sweet spot for Bat ID C6. This drop of 0.012 in the BESR value is equivalent to about a 2% drop in batted-ball speed in the field. The largest increase in performance for any of the composite bats after the initial test was only 0.001 in BESR at the sweet spot. This difference is within the variability of the test which is ±0.003. The aluminium bat (Bat ID M1) exhibited performance values of BESR at the sweet spot within 0.004 of the initial measured performance for each of the subsequent five performance tests.

Figure 2 shows how the change in maximum BESR value evolved with each set of 100 hits on the seven bats. For viewing convenience, the BESR axis has divisions of 0.007, which corresponds to a change of 0.45 m/s (1 mph) in batted-ball speed. The change in the maximum-BESR data are summarized in Table 1. Bat ID C6 showed the biggest change in performance with usage—a drop of 0.012 in the maximum BESR value. This drop of 0.012 was followed by an increase of +0.005. The bat then failed during the next 100-hit sequence. This up and down change in the BESR performance may be an indication of material degradation that eventually resulted with the bat developing a serious crack. Bat ID M1 is the aluminium bat, and its maximum BESR performance oscillated up and down within the resolution of the test—implying essentially no change in performance. The aluminium bat failed due to cracking in the barrel. Bat ID C1 exhibited the best durability by lasting 1000 hits. Its barrel showed little sign of material degradation. Bat ID C1 eventually failed in the handle—most likely as a consequence of low-cycle fatigue due to the alternating stresses developed in the handle during testing. After 100 hits and 400 hits, there were measurable changes in the performance of Bat ID C1. However, each of these measurable changes was a decrease in BESR relative the value measured on the new bat.

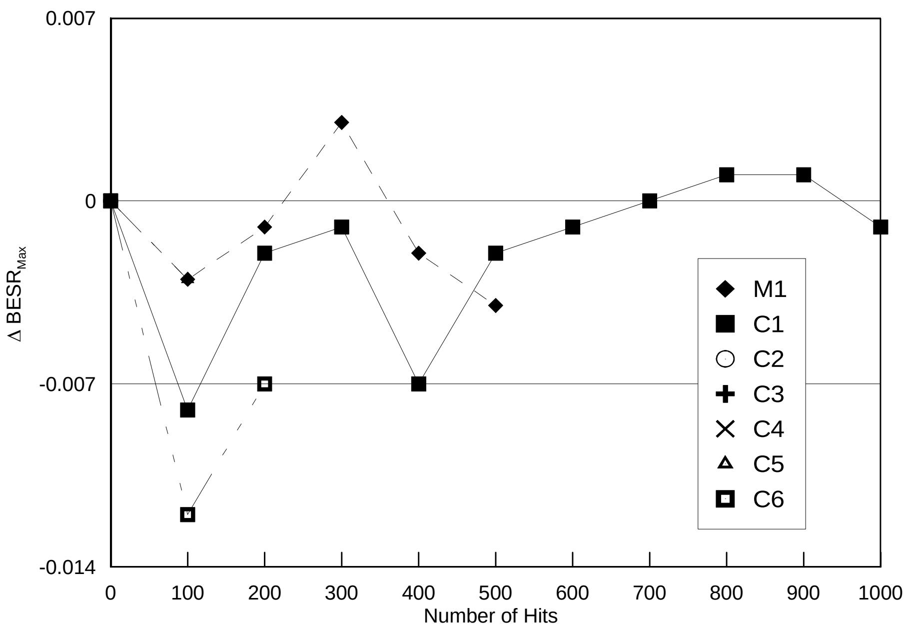

Figure 2: Change in Max BESR

Bat ID	Number of Hits										
	0	100	200	300	400	500	600	700	800	900	1000
M1	0.000	-0.003	-0.001	+0.003	-0.002	-0.004	--	--	--	--	--
C1	0.000	-0.008	-0.002	-0.001	-0.007	-0.002	-0.001	0.000	0.001	0.001	-0.001
C2	--	--	--	--	--	--	--	--	--	--	--
C3	0.000	--	--	--	--	--	--	--	--	--	--
C4	0.000	--	--	--	--	--	--	--	--	--	--
C5	0.000	-0.003	--	--	--	--	--	--	--	--	--
C6	0.000	-0.012	-0.007	--	--	--	--	--	--	--	--

Table 1: Change in Maximum BESR

An alternate method for analyzing the performance data is to look at the average BESR across the barrel of the bat. The average BESR is the average of the BESR values for the five axial locations tested. Figure 3 shows how the change in average BESR value evolved with each set of 100 hits. The average-BESR data are summarized in Table 2. Bat ID C6 shows the largest change with a drop of -0.007 in its average-BESR. None of the bats show a significant change in BESR performance relative to that of the new bat.

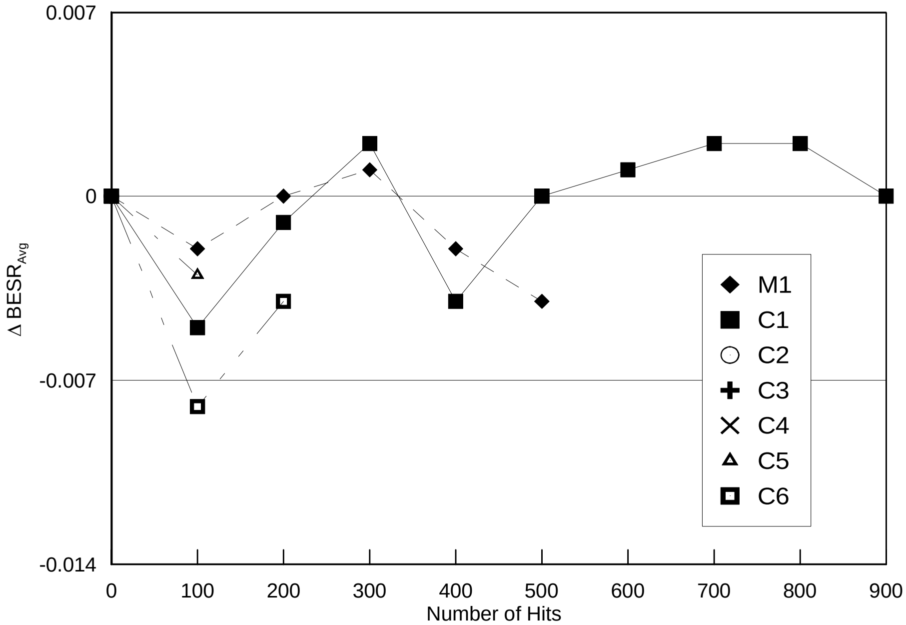

Figure 3: Change in Average BESR

Bat ID	Number of Hits										
	0	100	200	30400	500	600	700	800	900	1000	
M1	0.000	-0.002	0.000	0.001	-0.002	-0.004	--	--	--	--	--
C1	0.000	-0.005	-0.001	0.0.004	0.000	+0.001	+0.002	+0.002	0.000	0.000	
C2	--	--	--	--	--	--	--	--	--	--	
C3	0.000	--	--	--	--	--	--	--	--	--	
C4	0.000	--	--	--	--	--	--	--	--	--	
C5	0.000	-0.003	--	--	--	--	--	--	--	--	--
C6	0.000	-0.008	-0.004	--	--	--	--	--	--	--	

Table 2: Change in Average BESR

4- Conclusion

A set of six “high-performance” composite baseball bats and one aluminium baseball bat were tested to see how their respective batted-ball performances would evolve with use. None of the bats showed a significant change in the resulting batted-ball-speed performance using the NCAA BESR performance testing protocol. Three of the six baseball bats failed with less than 100 hits—implying that some of the composite bat designs are not durable.

5- References

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