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An investigation of bat durability by wood species

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Abstract

Northern white ash had been the wood of choice for Major League Baseball (MLB) bats until the introduction of hard maple in the late 1990s. Since the introduction of maple to the game, there has been a perceived increase in the rate of bats to exhibit multi-piece failures (MPF)—both ash and maple. Lab and field data indicate that while a maple bat is as equally likely to crack as an ash bat, maple is three times more likely than ash to exhibit an MPF. In 2009 MLB implemented a number of additional regulations and inspection processes for the wood billets in an effort to reduce the MPF rate. In 2010, another regulation was added requiring that before any new wood species can be introduced to the game, it must obtain approval from MLB Baseball Operations. This paper will describe a proposed wood species certification protocol to quantify its durability relative to ash, where ash is being taken as the acceptable baseline for durability. A demonstration of the protocol is conducted using yellow birch with white ash as the baseline. Finite element models of bats made of these two wood species are used to explore the relationship between wood density and bat durability.

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1. Introduction

Wood baseball bats have been breaking in Major League Baseball (MLB) games since the league originated over 140 years ago. With today's major league players having grown up using relatively thin-handle aluminum and composite bats and wanting the same relatively small handle size in their wood bats, the wood-bat breakage rate has appeared to increase in the last decade. Looking back, handle diameter is relatively smaller today than it was during the first 100 years of MLB. Because breakage rates

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were not tracked before July 2008, when MLB commenced a study on wood bat breakage, there are no data to describe if and how the breakage rate has evolved over time.

Wood bat failures are classified as either single-piece failure (SPF) or multi-piece failure (MPF). An SPF is defined as when a bat cracks but remains intact, while an MPF is defined as when a bat breaks into two or more significant pieces. In response to a perceived increase in the rate of MPFs, the Baseball Office of the Commissioner working in cooperation with the MLB Players Association appointed a technical team of wood and bat experts to investigate bat breakage rates and the phenomena leading to such failures during the latter half of the 2008 regular season and subsequently implemented changes to the Wooden Baseball Bat Specifications (WBBS) in late 2008 [1,2]. The following season, MPFs were reduced by ~30%, and this reduction is attributed to the new regulations. In 2010, the WBBS was amended to include a list of wood species acceptable for use in Major and Minor League Baseball, as well as species that are expressly prohibited. The list was created based on how wood species had performed on the field in the past. However, at that time, there was no defined set of criteria that a wood species must satisfy to be considered acceptable for Major and Minor League use. For this reason, the development of a test protocol and associated pass/fail criteria was requested of the technical team by the Office of the Commissioner of MLB and the Players Association for the certification of any new wood species before it could be used in MLB games.

The proposed method developed by the team consists of scientific testing processes which include durability testing, clear dowel testing, and batted-ball performance testing. Finite element modeling was conducted to assist in the interpretation of the durability test data as a function of wood density, wood species, wood slope of grain (SOG), impact location and impact velocity. To establish a baseline for wood durability and batted-ball performance, testing was initially performed on ash bats because ash had been the wood of choice until the entry of maple. Yellow birch has recently been used for MLB bats and was used as the “test case” for the proposed certification protocol.

2. Testing Methodology

Data were obtained for ash and yellow birch through durability, batted-ball performance and clear dowel testing. Finite element analyses were performed for yellow birch bats to assist in the durability test data interpretation and parametric studies.

2.1. Durability Testing

Durability testing was performed on ash and yellow birch bats using the Automated Devices Corporation (ADC) air cannon in the UMass-Lowell Baseball Research Center (UMLBRC). This machine can be used to shoot baseballs at velocities up to 200 mph (320 km/hr), and the target velocity (typically within ± 2 mph (± 3.2 km/hr)) can be attained by adjusting the air pressure of the burp cannon. Light gates measure the inbound velocity of the baseball and have an accuracy of ± 0.5 mph (± 0.8 km/hr). Low (less than 0.0225 lb/in³ (0.623 g/cm³)), medium (between 0.0225 and 0.0250 lb/in³ (0.623 and 0.692 g/cm³)), and high density (greater than 0.0250 lb/in³ (0.692 g/cm³)) bats were tested, and impacted at locations 2, 10, 14 and 16 in. (5.08, 25.40, 35.56 and 40.64 cm) from the tip of the barrel.

Two different durability testing processes were used. The majority of the testing was conducted using the standard durability testing procedure, for which the test speed of the ADC was set to the initial test-speed threshold anticipated for a specific impact location. The testing then continued in 5-mph (8-km/hr) increments (as long as the recorded speed was greater than the target speed minus 2.5 mph (4 km/hr)) up to the peak testing speed. A total of five impacts at the peak testing speed were made if the bat had not broken during the process of moving from the initial to peak test speeds. The testing ended when the bat

initially cracked or the test sequence was completed, i.e. the five impacts at the peak testing speed. One-strike durability testing was performed on some low-density ash bats to identify what impact velocities induce MPF at each of the four impact locations.

SPF-threshold and MPF-threshold velocities were established for each of the impact locations. These velocities varied for different impact locations because of the different failure modes that occur and different swing speeds that can be produced at each location. The SPF and MPF threshold velocities were established based on what impact velocities have a strong likelihood of inducing an SPF or MPF in ash baseball bats for each impact location. A table of the threshold velocities that were established for each impact location is displayed in Table 1.

Table 1. Durability Threshold Velocities

Location from tip of barrel [in (cm)]	Velocity [mph (km/hr)]	
	SPF Threshold	MPF Threshold
2 (5.08)	125 (201)	170 (274)
10 (25.40)	135 (217)	160 (258)
14 (35.56)	110 (177)	130 (209)
16 (40.64)	105 (170)	135 (217)

The purpose of the durability testing of the ash bats was to determine the threshold velocities for the testing of new wood species which is based on a wood species that has been accepted in MLB as the gold standard for wood bats. Fifteen low-, medium- and high-density yellow birch bats were tested for durability; three bats of each density class were tested at the 2-, 10-, and 14-in. (5.08-, 25.40- and 35.56-cm) locations, while the six remaining bats of each density class were tested at the 14-in. (35.56-cm) location. More bats were tested at the 14-in. (35.56-cm) location than any of the other impact locations because MPFs that occur from these impacts tend to cause significantly large bat fragments to fly into the field and/or into the stands.

The type (SPF or MPF) number of failures that were induced at velocities below the established SPF and MPF thresholds for each density class and each impact location are summarized in Table 2. Table 2 shows that most of the yellow birch bats either did not experience any type of failure, or experienced SPF/MPF at velocities greater than the respective threshold for that impact location. One notable observation is that two out of the three of the high-density bats that were tested at the 16-in. (40.64-cm) location experienced an MPF at velocities below the MPF threshold for this impact location. While this result may be a statistical anomaly due to the low number of bats tested in this density class, this result could also indicate that high-density yellow birch is not as durable as high-density ash at this location. Two MPFs of low-density yellow birch occurred at velocities lower than the MPF threshold (one at the 2-in. (5.08-cm) and one at the 16-in. (40.64-cm) location). However, such breaks are not unusual, as the slight variations in the wood from bat to bat can result in break-speed scatter.

Table 2. Yellow Birch Durability Relative to SPF and MPF Thresholds

Test Location [in]	Low-density		Medium-density		High-density	
	SPF	MPF	SPF	MPF	SPF	MPF
2 (5.1)	0/3	1/3	0/3	0/3	0/3	0/3
10 (25.4)	0/3	0/3	0/3	0/3	0/3	0/3
14 (35.6)	0/6	0/6	0/6	0/6	0/6	0/6
16 (40.6)	0/3	1/3	0/3	0/3	0/3	2/3
Total	2/15		0/15		2/15	

2.2. Performance Testing

The velocity at which baseballs rebound off ash and yellow birch baseball bats was measured through performance testing. A total of 12 ash and 12 yellow birch bats were tested for batted-ball performance. Six bats of each wood species were low density (<0.0225 lb/in³ (0.623 g/cm³)), and six are high density (>0.0275 lb/in³ (0.761 g/cm³)). Performance testing was conducted using an air cannon that propels the ball using a sabot. The performance metric chosen for this research was the Batted-Ball Coefficient of Restitution (BBCOR), which is defined in ASTM Standard F-2219 [3].

Each bat was impacted at several locations along the barrel to isolate the sweet spot (peak performance) to document how the batted-ball performance varies on either side of the sweet spot. A bat is first impacted at the 6.0-in. (15.2 cm) location (as measured from the tip of the barrel) with a baseball fired at a speed of 136 ± 2 mph (219 ± 3 km/hr). The BBCOR value for a given location is an average of six valid measurements. The process continued at other locations (impact speed adjusted accordingly to account for change in bat velocity at different impact locations) to isolate the sweet spot location and to determine the performance of locations off the sweet spot. Sweet spot isolation was performed on three high- and three low-density bats of each species, during which six valid measurements were made at the highest performing location of the barrel, and six valid measurements were made at the locations ± 0.5 in. (± 1.27 cm) from the sweet spot. Following the performance testing protocol sometimes resulted in measurements being obtained at additional locations. The testing of the remaining bats required that six valid impacts be obtained at the location that was determined to be the sweet spot, followed by attempting to obtain six valid measurements at locations ± 2 in. (± 5.08 cm) and ± 3 in. (± 7.62 cm) from the sweet spot. The bats that were tested would often break before six valid impacts were obtained at each location, but as much data as possible were obtained. The obtained data are summarized in Table 3.

Table 3. Composite BBCOR Measurements at Different Impact Locations

Location [in] (cm)	BBCOR HD Ash	LD Ash	HD YB	LD YB
3.5 (8.9)	0.403	-	0.409	-
4.5 (11.4)	0.450	0.449	0.442	0.451
5.5 (14.0)	0.470	0.474	0.471	0.471
6.0 (15.2)	0.476	0.479	0.477	0.477
6.5 (16.5)	0.481	0.480	0.481	0.477*
7.0 (17.8)	0.478	0.476	0.476	0.473
7.5 (19.1)	0.468	-	-	-
8.5 (21.6)	0.435	0.428	0.452	0.435
9.5 (24.1)	0.401	-	-	-

* Sweet spot determined to be at 6.5-in. (16.5-cm) location during isolation

Table 3 shows that the sweet spots of all high- and low-density ash and yellow birch bats were at the 6.5-in. (16.5-cm) location. Table 3 also shows that high-density bats tend to outperform low-density bats at locations near the sweet spot, while at locations farther away the differences are more significant.

2.3. Finite Element Modeling

Finite element modeling was performed to assist in the analysis of experimental yellow birch data [4]. Specific bats that went through the durability testing process were modeled. The materials properties, including MOE (Modulus of Elasticity), MOR (Modulus of Rupture), density and slope of grain, applied to each model with the velocity that induced failure. The MOE and MOR values that were prescribed in each model were determined from examining the four-point bending test results of clear dowel samples of

both wood species [5]. These tests showed that there is an essentially linear relationship between the wood density and both the MOE and MOR of each species. Regression analyses were used so that the MOE and MOR values that are associated with each density class could be extracted and applied to the appropriate models. The MOE and MOR values of yellow birch were higher than those of ash for each density class, which is desirable.

Another important modeling input is the failure strain, but this cannot be experimentally determined through durability or dowel testing. For this reason, multiple bat models with different failure strains were run until the finite element modeling results correlated well with the durability testing results. It was initially believed that the relationship between failure strain and density would follow a somewhat linear trend. However, modeling showed that while failure strain for low-density bats (3.5%) is lower than for medium-density bats (4.6%), medium- and high-density bats have the same failure strain. A few examples of the correlation between analytical and experimental results using these failure strains are displayed in Figure 1.

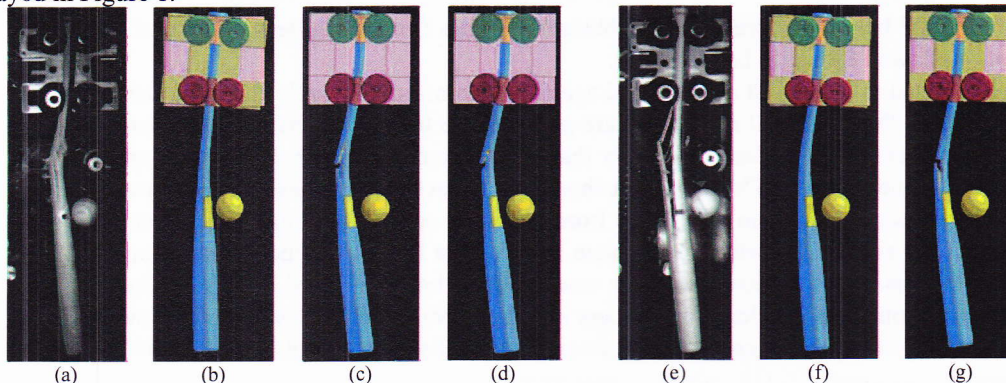


Fig. 1. Comparison between breakage observed from durability testing and finite element modelling; (a) Yellow birch bat of density 0.601 g/cm^3 and 0.0° SOG impacted at 14-in.(35.6-cm) location, maximum velocity without break was 134 mph (216 km/hr), bat broke at velocity of 147 mph (237 km/hr); (b) FEA model of same bat impacted at 135 mph (217 km/hr) with strain to failure of 3.5%, bat did not break; (c) FEA model of same bat impacted at 140 mph (225 km/hr) with strain to failure of 3.5%; (d) FEA model of same bat impacted at 135 mph (233km/hr) with strain to failure of 3.5%;(e) Yellow birch bat of density 0.662 g/cm^3 and -0.3° SOG impacted at 14-in.(35.6-cm) location, maximum velocity without break was 156 mph (251 km/hr), bat broke at velocity of 150 mph (241 km/hr); (f) FEA model of same bat impacted at 150 mph (241 km/hr) with strain to failure of 4.6%, bat did not break; (g) FEA model of same bat impacted at 155 mph (249 km/hr) with strain to failure of 3.5%

Finite element modeling of breaks that occurred at the 16-in. (40.64-cm) location were also performed to validate the failure strains used for each density class. The failures observed experimentally correlated reasonably well with the analytical models.

3. Summary of Proposed Wood Species Evaluation

The testing results that were obtained were used by the technical team to develop a process for evaluating a new wood species for use in baseball bats. After background information is provided about the proposed species, a preliminary durability test of twelve low-density {weight less than 31.0 oz (0.9 kg), length $34.0 \pm 0.2 \text{ in.}$ ($86.4 \pm 0.5 \text{ cm}$)} bats (six each of models C243, C271) is performed. All bats are impacted at the 14-in. (35.56-cm) location. It is proposed that a species passes the preliminary testing stage if two or fewer bats experience MPF at velocities above 130 mph (209 km/hr), which is the MPF threshold at this location.

Preliminary testing is followed by dowel sample testing. One-hundred eighty dowel samples will undergo a four-point bend test, of which 60 each are low (less than 0.0220 lb/in^3 (0.623 g/cm^3)), medium

(between 0.0220 and 0.0250 lb/in³ (0.623 and 0.692 g/cm³)) and high density (greater than 0.0250 lb/in³ (0.692 g/cm³)). Thirty dowels of each density class had a diameter of 0.94 in. (2.39 cm), and the remaining dowels had a diameter of 0.86 in. (2.18 cm). The MOE and MOR as a function of density will be plotted, and the minimum MOE and MOR values for typical wood bat density ranges must not be less than that of ash. Finite element modeling will be used to determine if the geometry of C243 or C271 baseball bats in combination with the range of MOR and MOE values of a species, as determined by dowel testing, identifies any durability characteristics.

A full complement of dynamic bat testing is then the next step in the process. The durability testing has 15 low- (0.0200 – 0.0225 lb/in³ (0.544 – 0.623 g/cm³)), 15 medium- (0.0225 – 0.0250 lb/in³ (0.623 – 0.692 g/cm³)), and 15 high-density (0.0250 – 0.0275 lb/in³ (0.692 – 0.761 g/cm³)) C243 bats run through the standard durability testing process. Three bats from each density class are to be impacted at the 2-, 10-, and 16-in. (5.1-, 25.4-, and 40.6-cm) locations, while the remaining six bats of each class are to be impacted at the 14-in (35.56-cm) location. It is proposed that if more than 2 of 15 bats of any density class experience SPF or MPF below the thresholds established in Table 1, then that density class of that wood species will not be allowed for use in baseball bats.

Performance testing is used to identify if a new wood species performs significantly different than the typical bat carved from ash. Twelve M110 model bats are performance tested. Six bats are low density (less than 0.625 g/cm³), and six are high density (greater than 0.761 g/cm³). Three bats of each density class are tested to isolate the sweet spot. The remaining three bats of each density class will be tested at the sweet spot, and then at locations ± 2.0 in. (± 5.1 cm) from the sweet spot. All of the BBCOR values obtained at each location are averaged together to calculate and average BBCOR value for each density class at the different locations. It is proposed that the wood species be categorized by the maximum average BBCOR value of both high and low density bats and the average BBCOR value of the sweet spot, ± 0.5 in. (± 1.3 cm), and ± 2 in. (± 5.1 cm). It was found that ash bats would not exceed 0.484 and 0.470 for the maximum and average BBCOR values, respectively.

4. Conclusion

The proposed method for accepting a new species of wood consists of comparing the durability and performance of a proposed species against white ash, the benchmark species for wood bats. Durability testing would consist of determining at what velocity SPF and MPF occur for a proposed species relative to ash. Performance testing would determine if a proposed species provides a competitive advantage by outperforming ash bats. Dowel testing and finite element modeling would be used to determine the MOE, MOR, and failure strains of a species, respectively. The testing of yellow birch as a trial species showed that its durability, performance, and material properties are all similar to ash, and therefore it is adequate for use in MLB play.

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