The Effects of Moisture Content and Workhardening on Baseball Bat Performance

P.J. Drane & J.A. Sherwood
Baseball Research Center, Department of Mechanical Engineering
University of Massachusetts Lowell, Lowell, Massachusetts USA

ABSTRACT: In recent years, baseball bat performance has come under scrutiny. Fans of Major League Baseball have seen homerun records broken and the governing organizations of both college and high school baseball have stepped in with tighter controls of baseball bat performance. This paper discusses a few of the ways that baseball bat performance is affected by changes in the material and physical properties of the bat. The scope of the paper includes the effects of moisture content on the performance of solid wooden bats, which are used for professional baseball in the United States, and the effects of workhardening on the performance of aluminum bats, which are used by high school and college players. The results from the moisture content tests of wooden bats showed that an increase in the moisture content by soaking the bats in humidified air resulted in a small increase in the batted-ball performance. Across the positions on the bat, which were tested, the resulting increase reached a maximum of about 1%. The repeated hitting of an aluminum bat with the intent of workhardening it also showed an increase in batted-ball velocity of about 2%. Though, neither of these changes is enormous, they easily could be the difference between the warning track fly-out and a homerun.

INTRODUCTION

It is believed that Abner Doubleday first developed the game of baseball in 1839. Though the method of playing baseball has not significantly changed since, the equipment used has. Most of the equipment changes have made the game safer for the players, e.g. batting helmets, shin guards, face masks. Some changes have made the game more exciting, e.g. the increasing of the liveliness of the baseball when Babe Ruth was playing. For the most part these changes have been for the better by making the sport healthier for the players and more exciting for the spectators. In recent years, some of these changes were beginning to affect the game adversely, by increasing safety risks and leading to homerun derbies. The introduction of high-performance aerospace-quality aluminum alloys and composites into baseball bats used in many amateur leagues led the National Collegiate Athletic Association (NCAA) to restrict the performance of the bats used in NCAA baseball in 2000. The NCAA developed a testing protocol for measuring the performance of the baseball bat for certification purposes. A summary of the NCAA testing protocol (1999) is shown in Fig. 1. A schematic of the testing apparatus is shown in Fig. 2. The certification testing is performed at the University of Massachusetts Lowell Baseball Research Center (UMLBRC).

Though professional baseball has never allowed baseball bats to be constructed of materials other than solid wood, they have faced their own performance related stories. In

1998, fans of Major League Baseball (MLB) were captivated by the contest between Sammy Sosa and Mark McGuire to break the record of 61 homeruns in a season, which was intact since 1961. The race ended with a new record of 70 homeruns in a season by McGuire. In the 2001 season, the homerun record was again eclipsed with a 73-homerun performance by Barry Bonds. Fans are beginning to question how a record that was unbreakable for 27 years is now being routinely broken.

To determine some of the characteristics that affect baseball bat performance, the UMLBRC has conducted academic research in conjunction with MLB and NCAA. MLB is concerned only with wooden bats because major league players are only allowed to use a bat made of a solid piece of wood. The NCAA is concerned mainly with aluminum bats because they are the preference for the majority of college players, and NCAA batting statistics increased dramatically with the introduction of aluminum bats in 1974.

Summary of NCAA testing protocol

1) Environmental test conditions –
   a. Relative Humidity - 50±15 %
   b. Temperature - 75±10 °F
2) Baseball bat speed - 66±1 mph (as measured at point 6 in from tip of barrel)
3) Baseball pitch speed - 70±2 mph
4) Batted-ball speeds measured at 9 inches, 13 inches, and 6 feet from impact
5) Valid hits must have
   a. Baseball and Baseball bat speeds in required range
   b. Either the 9-in or 13-in batted-ball velocity higher than the 6 foot reading
   c. Good targeting on trajectory

6a) Aluminum - 5 valid hits obtained at 5.0, 5.5, 6.0, 6.5, and 7.0-inch locations from the barrel end of the bat

6b) Wooden – 3 to 5 valid hits at 5.5, 6.0, and 6.5-inch locations from the barrel end of the bat

Fig. 1 Summary of NCAA test protocol

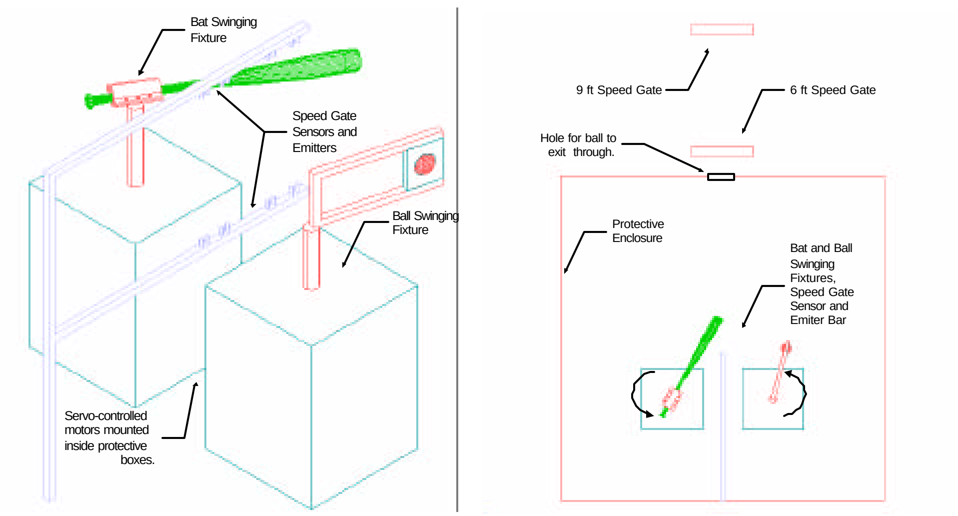

Fig. 2 Schematic of testing apparatus (Baum Hitting Machine)

EFFECTS OF MOISTURE CONTENT

Climates vary considerably across the United States. Additionally, the sport of baseball at the major league level is played from the beginning of April to the end of October. The springs in Boston are cool and wet, while the summers in Phoenix are hot and dry. Different baseball stadiums will, therefore, expose wooden bats to different conditions at different times of the year. *The Wood Handbook* (1999) published by the Forest Products Society identifies the equilibrium moisture content for Phoenix, Arizona in the month of June to be 4.6% on average, whereas Los Angeles, California is 15.1% in the month of August. Though many baseball bats may not be exposed to the environment long enough to come into equilibrium with these extremes, the bats which are stored in the environment for even a few days will show a change in moisture content. It is, therefore, important to determine the effects that a change in moisture content will have on wooden baseball bat performance. Wood bats are typically kiln dried. During this drying process the cellular structure of the wood changes due to chemical reactions. The simple forcing of moisture back into the wood by soaking the bats in very humid air does not produce the same material properties as would result from drying wood from its green state to that moisture level.

One method used for determining the effects of a change in moisture content of a baseball bat is to test the same bat at two different levels of moisture content. Another method uses different bats, which when tested, have the same physical properties, i.e. length, weight, balance point, except for different moisture contents. The benefit of the first method is that the variations in the properties of woods are essentially eliminated because both the dry and the moist tests are performed on the same bat. This method requires a "swing correction" to predict the actual field performance. The other method introduces the potential variability of testing two bats that may have different dynamic properties due to inherent variations in natural wood. The first method is modeled after a player who has a favorite bat and uses it in different cities and climates. The second method is modeled after a player who has a number of bats and prefers to choose a bat that gives him the same feel no matter where he is playing the game of baseball.

SAME BAT METHOD

Fig. 3 shows results that obtained by testing a 33-inch ash baseball bat. The surface of this bat is unfinished--allowing the moisture to penetrate the surface with very little resistance. Prior to the test, the bat had been stored in a room kept at 50% relative humidity according to standard protocol. The bat was then stored in an environment that averaged 85% R.H. for 17 days. The Baum Hitting Machine, which swings both the baseball bat and the baseball into the hit and measures the incoming velocities of the bat and the pitched ball and the batted-ball velocity, was then used to investigate the batted-ball velocities at the three standard test positions (as denoted in Fig. 1) on the bat. The bat was subsequently allowed to dry in the room kept at 50% R.H. and was tested again using the Baum Hitting Machine at the same three positions.

The tests were performed on the wooden bat while it had moisture contents of both 10.9 and 6.7%. The moisture content was recorded as the average of the measurements taken on the barrel of the baseball bat. Fig. 3 shows the averages of the batted-ball velocities as measured at the 6-foot location from impact for each of the three positions tested on the bat. The weight is less for the test specimen with less moisture. Therefore, the bat with a moisture content of 6.7% can actually be swung in the field with a higher velocity than the bat with a moisture content of 10.9%. Therefore, an adjustment was made for the swing speed taking into consideration the change in moment of inertia (Fig. 3). Assuming that the moment of inertia introduced its most significant effects when the bat is fully extended and rotating primarily about the center of the grip of the baseball bat and that there is conservation of energy, the change in swing speed can be approximated using eq. 1;

$$?_{dry} = ((I_{moist} * ?_{moist}^{2})/I_{dry})^{1/2} \quad (1)$$

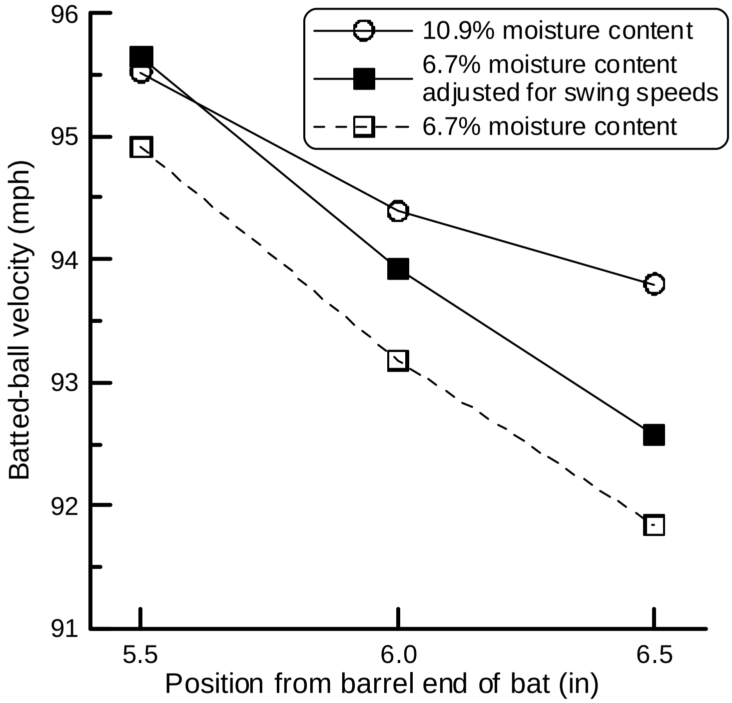

Fig. 3 Performance of a wooden bat tested at different moisture contents

where $?_{dry}$ and $?_{moist}$ are the angular velocities of the dry and moist bats, respectively, and I_{dry} and I_{moist} are the mass moments of inertia (MOI) about the position 6-inches in front of the knob of the bat for dry and moist bats, respectively. The MOI for the moist sample was 11,313 [oz-in^2]. The dry sample had an MOI of 11,001 [oz-in^2]. Because the baseball bat speed for the moist sample was 66 mph, the resultant bat speed for the dry bat swung by the same player would be 66.9 mph. This increase of 0.9 mph would generally lead to about a 0.75 mph increase in batted-ball velocity. Therefore, the dry sample has been graphed with the 0.75-mph offset to compare the change in performance as predicted by the machine setup for this particular bat being used after having been exposed to a different climate.

Prior to the adjustment for swing speed, the baseball bat with the higher moisture content had a distinct increase in performance over the "dry" bat. With the adjustment for swing speed, the results show that the bat with the higher moisture content has a higher performance by as much as 1% along the tested region.

SAME WEIGHT METHOD

The second method for investigating wood bat performance was performed in a similar way to the first method. A bat was stored in an environment that was maintained at an average of 85% R.H. for a 17-day period. It was then tested at the 5.5, 6.0 and 6.5-inch locations.

Then another bat, which had been stored in the standard lab environment of 50% R.H. and had a similar MOI and weight, was tested at the same three positions. The results from these two tests can be seen in Fig. 4.

The results from testing moisture content using this same-weight method are very similar to the results obtained by the same-bat method. Because both of the bats used in the same-weight testing have essentially the same MOI, they will be swung with the same velocity. Therefore, there is no need for any adjustments due to differences in swing speed to be made to the data. This combination of bats shows the bat with a 10.9% moisture content to have as much as 1% increase in performance over the drier bat with a 6.7% moisture content (Fig. 4).

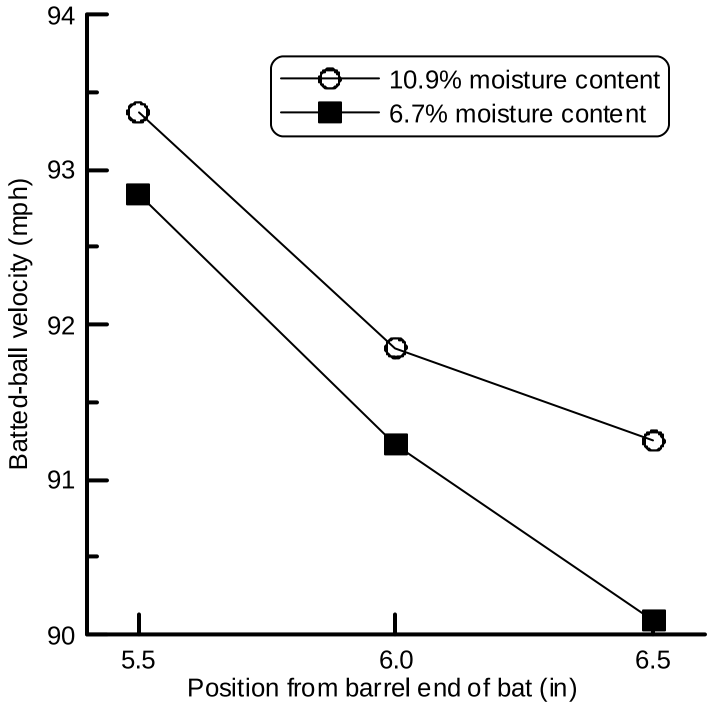

Fig. 4 Performance of bats with same MOI but different moisture contents

EFFECTS OF WORKHARDENING

Players and bat manufacturers commonly argue that the performance of aluminum baseball bats deteriorates with increased use. Theories of stress, strain and workhardening predict a conflicting result. Workhardening can occur when a metal is deformed beyond its elastic limit. The deformation, on the microstructural level, results in dislocation generation and movement, and results in a stronger metal from a yield point perspective on the macroscopic level. As a baseball bat surface workhardens, more elastic energy is stored in the bat that can be transferred to the batted-ball, giving the ball more energy than the non-workhardened bat and hence, the workhardened bat exhibits an increased performance.

The NCAA requires each length/weight/model combination of bat to be tested for compliance with its bat-performance rule. In 1999, the NCAA mandated that non-wood bats could perform no better than 34-in. bats made of northern white ash. The UMLBRC is the official certification center for such compliance testing. Thus, manufacturers send new production bats to the UMLBRC for certification, and the NCAA submits bats pulled from field service to test for compliance. If a given length/weight/model bat combination workhardens as it is used during a season, then that combination could potentially pass the certification process, but exceed the established performance limit during the season. Therefore, the NCAA is interested to know the effects of workhardening of aluminum baseball bats.

The test method used for measuring the performance of an aluminum baseball bat as a function of repeated hitting involves performing consecutive certifications on a single baseball bat. Each certification includes five valid hits at all five positions on the barrel end of the bat according to standard protocol. Such testing on the hitting machine can be considered to be representative of field-service use.

Each data point plotted in Fig. 5 represents the average of all 25 valid hits during certification of a standard 33-inch aluminum bat made of C405 aluminum. The data are generated from the 9-inch and 13-inch measurements and are normalized based on a comparison to the pass/fail limit used for the certification of baseball bats. This comparison is necessary because different lots of baseballs were use throughout the tests. A total of 830 hits were taken on the bat before it was ultimately destroyed due to the appearance of large cracks in the barrel. A fifth-order polynomial fit of the data is included in the plot to show the trend of the data. The data imply that the most significant performance increase occurs near the beginning of the bat's life (after about 120 hits). The dashed lines indicate several notable visual changes in the bat's surface. At about 600 hits, stress marks appeared on the surfaces that are between the 5.0 and 7.0-inch marks. The appearance of these stress cracks corresponds to a secondary increase in performance. As the bat was approaching 770 hits,

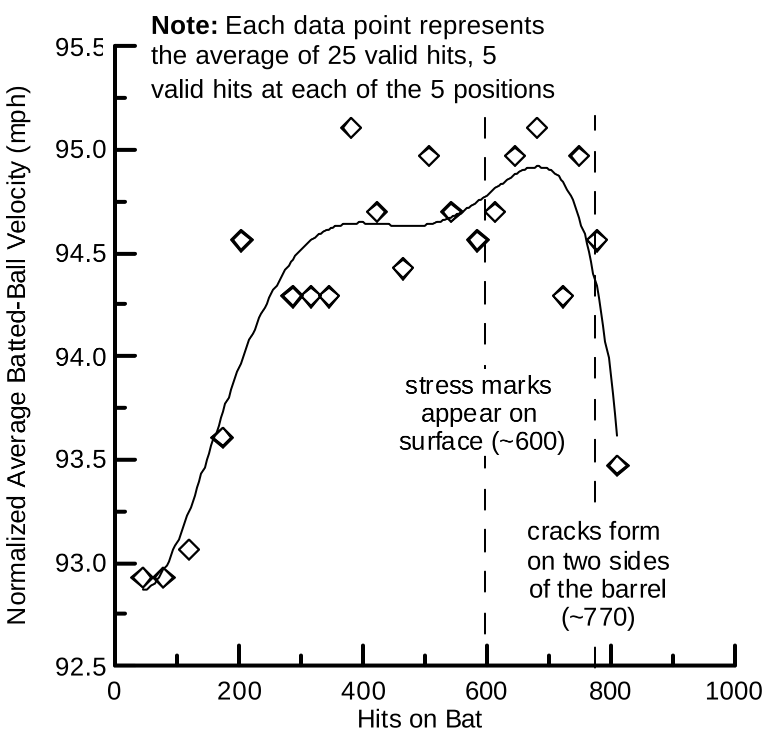

Fig. 5 Performance of aluminum baseball bat through repeated hitting

the surface on two sides of the bat had cracks running axially. This observation coincides with the beginning of the steep decline in the bat performance. Overall, the performance of the work-hardened aluminum baseball bat showed an increase of about 2% from its original performance.

Workhardening may not always occur. Another bat was tested under a similar process. After 147 hits on the 33-inch baseball bat constructed of C555 aluminum, the surface had dented so significantly that testing could not continue. Up to that time, the bat's performance had decreased slightly, and the Rockwell hardness had also decreased. The results from these two workhardening tests identify that workhardening may increase the performance by about 2% if the bat remains in good condition for a significant number of hits.

CONCLUSIONS

Both moisture content and workhardening can have an effect on the performance of baseball bats. The same-bat method and same-weight method used to determine the effective change in performance from moisture content both showed an increase with a maximum of about 1% when the moisture content went from 6.7% to 10.9%. The result of the workhardening of an aluminum baseball bat identified that an increase of about 2% in performance is possible if the bat remains in good condition through a significant amount of use.

REFERENCES

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NCAA PROVISIONAL STANDARD FOR TESTING BASEBALL BAT PERFORMANCE *(1999) http://www.ncaa.org/releases/miscellaneous/1999092901ms.htm*