Comparison of the performance of U.S. and Japanese aluminum baseball bats

S. Nabeshima and J.A. Sherwood
Baseball Research Center, Department of Mechanical Engineering
University of Massachusetts Lowell, Lowell, Massachusetts, USA

ABSTRACT: In 1998, the National Collegiate Athletic Association (NCAA) took steps to develop a scientific test methodology to measure and to control baseball bat performance. The resulting standard uses a hitting machine that pitches a ball at a moving bat to measure the BESR (Ball Exit Speed Ratio). Concurrently, the governing body for amateur baseball in Japan developed a test protocol for controlling bat performance. In contrast to the NCAA test methodology, the Japanese protocol uses a series of static tests. This paper compares the two protocol philosophies and presents experimental data highlighting the respective criteria of each approach and discusses how successful each approach has been in controlling nonwood baseball bat performance. Comparison data and analysis showed that some Japanese bats marginally outperformed U.S. bats with respect to batted-ball speed. Despite the lack of direct restriction on batted-ball performance using a dynamic test method, the Japanese regulation is controlling the performance of aluminum bats fairly well.

INTRODUCTION

Since the inception of baseball and up through the latter part of the 20th century, wood was the material for baseball bats. While wood bats are traditional to the game of baseball, they have relatively low durability as they tend to crack in the handle and flake in the barrel. In the 1970s, several bat manufacturers started to produce aluminum bats as a means to address durability and thereby reduce overall operating costs for amateur baseball teams. In 1974, the National Collegiate Athletic Association permitted the use of aluminum bats in its baseball games with the understanding that the game would remain essentially the same while reducing operation expenses. Though the cost reduction in purchasing bats was achieved, the introduction of aluminum bats eventually brought concerns over two issues: the safety of baseball players and the balance of defense and offense. As the technologies around aluminum bats advanced with time (i.e., high-strength aluminum alloys combined with thin walls), the performance of the bats improved as observed by ever increasing batted-ball speeds. The increase in the ball exit speed translates to the potential increase in the severity of the injury of players being hit by batted balls. The improvement of aluminum bats in batted-ball performance potentially allows batters to hit homeruns more readily. Thus, offense gains advantage over defense, and the balance of the game is compromised.

The solution to maintain the integrity of baseball while continuing to use aluminum bats is to control the balance between defense and offense. This balance is achieved by using aluminum bats that perform similar to wood bats. In September 1999, the NCAA introduced a three-prong bat rule. One prong limits the maximum size of the barrel to 2.625 in, and the second prong limits the difference between the length in inches and the weight in ounces (oz) to be no greater than 3 units (e.g. 34 in and 31 oz). These two prongs make the aluminum bats physically comparable to their wood counterparts in size and weight, but do not necessarily do anything to control batted-ball speeds. The third prong limits the batted-ball performance of aluminum bats. To measure the performance of bats, the NCAA introduced a new parameter called the Ball Exit Speed Ratio (BESR), and the BESR of any nonwood bats for the NCAA baseball games cannot exceed the BESR limit as established by the best performing wood bat. In 2000, the NCAA added a minimum MOI (moment of inertia) prong to keep the swing weight of aluminum bats similar to wood bats.

The "side effects" resulting from the introduction of aluminum bats are not unique to the United States. In 2001, the official Japanese baseball playing rules committee decided to add a new regulation to set the maximum allowable barrel diameter and the minimum allowable weight of aluminum baseball bats (“Rule Revision”, 2001). This regulation was similar to what the NCAA introduced in the U.S. for the 1999 baseball season—maximum barrel diameter of 2.625 in and 3-unit difference between length and weight. This regulation was established to decrease the performance of aluminum bats as an addition to three tests mandated in 1986, which were a three-point bending test, a wedge test, and a barrel compression test (JHBF, 2004). The primary purpose of these three tests was to prevent low-durability aluminum bats, which were the concern at that time in Japan. Though the primary purpose of these tests is not to regulate the performance, the barrel compression test is performed for regulating the resiliency of bats, which is one of the factors that can affect the batted-ball performance of baseball bats.

The current study compares the batted-ball performance of aluminum bats sold respectively in the U.S. and Japan and designed to satisfy the respective protocols for each country. To support the performance test results, various factors such as MOI, wall thicknesses, and modal node points, which may affect the performance of those bats, are examined. The comparison study gives insight as to what level each protocol restricts aluminum bat performance.

COMPARISON METHOD

The methods used in this study to compare the U.S. and Japanese aluminum bats were employed using the protocols of both countries. The first test performed was the BESR certification method. The BESRs of bats are calculated from the bat entry speed, the ball pitch speed, and the ball exit speed resulting from testing the bat in the Baum Hitting Machine (BHM) as shown in Fig. 1, which is capable of “pitching” a ball into a swinging bat at specified speeds.

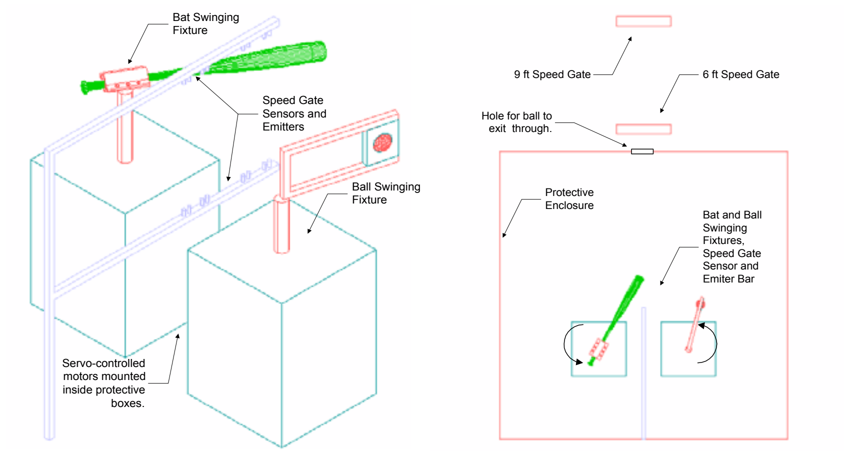

Fig. 1 Schematic of BHM (Mustone and Sherwood, 1998).

The BESR is calculated using Eq. 1 (NCAA, 1999):

$$\text{BESR} = [v^* - (V-v) / 2] / (V+v) \tag{1}$$

where v*, V, and, v are the ball exit speed, the bat entry speed at the 6-inch point from the tip of the barrel of the bat, and the ball pitch speed, respectively. Using the BESR certification protocol as a basis, five valid hits were taken at each of five locations; 5.0, 5.5, 6.0, 6.5, and 7.0 inches from the tip of the barrel on each bat. Based on the data obtained from the BESR certification method, the data obtained from other types of tests were compared. The data from the BESR certification method are the only data that show the direct comparison of the performance between the Japanese and U.S. aluminum bats in this study.

The second test performed was the barrel compression test, which is one of the required tests for aluminum bats to be certified per the SG standard (where S denotes "Safety", and G denotes "Goods") compliant with the Consumer Product Safety Association (CPSA, 2000) in Japan. The CPSA governs all aluminum bats for all levels of baseball in Japan. The purpose of this test is to investigate the resiliency and the durability of the barrel of a bat. To perform this test, the barrel of a bat was cut into three 50-mm long rings as shown in Fig. 2. Then a force was applied on each ring by using an Instron testing machine with a 5000-lb (22,241-N) load cell until the deformation of the ring reached $0.2D_0$, where D_0 was the maximum original outer diameter of the ring. During the compression test, the ring was placed on an adjustable base so that the normal force would be applied to the ring as shown in Fig. 3. The force was applied on the ring until the force reached 10,000 N. From the load-deflection curve obtained from the test, the load corresponding to a residual deformation of $0.02D_0$, which is called "offset load" in this paper, was found (Fig. 4). For an aluminum baseball bat for general players, which are defined as high school students or older players, the offset load must be equal to or greater than 7500 N to pass the SG standard.

Fig. 2 Three rings taken from the barrel of a bat

Fig. 3 Barrel compression test on a ring by an Instron machine.

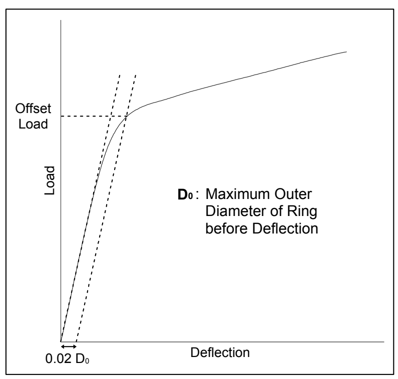

Fig. 4 Offset Load from Load -vs.- Deflection Curve.

RESULTS

In this study, eight SG compliant bats, called "Japanese bats" in this paper, and three BESR certified bats, called "U.S. bats" in this paper, were tested by utilizing the methods specified in the respective protocols.

Fig. 5 shows the respective average of the performance levels at each axial location for eight Japanese bats and three U.S. bats. As seen in Fig. 5, the two curves have similar trends, having sweet spots in the region of the 5.5-in and 6.0-in positions and the lowest performance at the 7.0-in position. However, the average of the Japanese bats is about 1 mph greater than that of the U.S. bats.

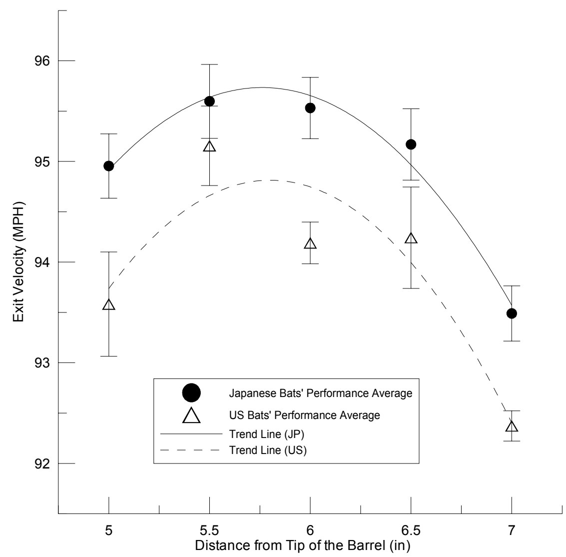

Fig. 5 Comparison in performance average of U.S. and Japanese bats.

Fig. 6 shows the relationship between the maximum exit speed of each bat and the offset load. The quadrants are separated by two limits—the BESR-based maximum exit speed limit and the lowest offset load requirement—and denote the compliance to the respective regulations. The results show that four of the eight Japanese bats performed within the BESR limit. None of the U.S. bats passed the offset load requirement. Statistical certainty of these Japanese-compliance results are presented in horizontal error bars, representing the standard error of the mean of offset loads, and the statistical certainty of BESR-compliance results are presented in vertical error bars, representing the standard error of the mean of exit velocities.

Fig. 7 shows the relationship between the performance and the MOI of the bats. The solid circles and the open triangles denote the original maximum exit speed of the Japanese bats and the U.S. bats, respectively. The original BHM maximum-exit-speed data should not be viewed as representative of field performance because the BHM swings all of the bats at the same velocity regardless of MOI. Therefore, the BHM may output higher performance for higher MOI bats than would be seen in typical use, and vice versa for relatively low MOI bats. To include the effect on performance due to MOI difference, an empirical relation between a change in MOI and a change in swing speed is considered by using Eq. 2 (Fleisig *et al*., 2002) and a modified BESR equation shown in Eq. 3.

$$\triangle V_t = (-6.6 \cdot 10^{-4}) \cdot (\triangle \mathrm{MOI}) \quad (2)$$

$$v'_b = \mathrm{BESR} \cdot (V + \triangle V_t + v) + (V + \triangle V_t + v) / 2 \quad (3)$$

where $\triangle V_t$ is change in swing speed at 6-in location (mph) due to MOI, v'_b is batted-ball velocity (mph), V is the original bat swing speed (mph), and v is the ball entry speed (mph).

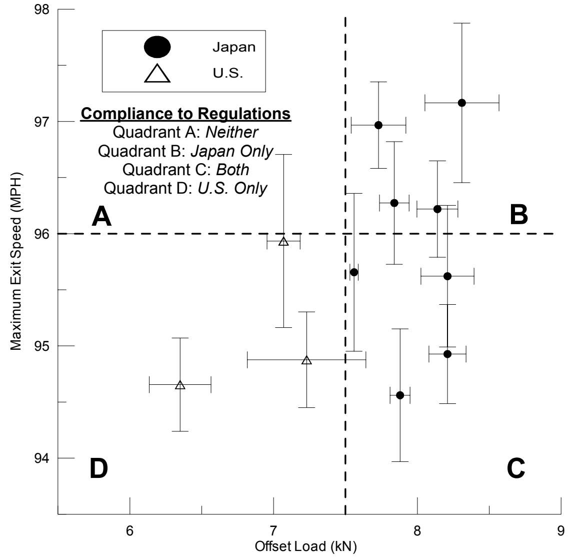

Fig. 6 Performance distribution by offset load and ball exit speed.

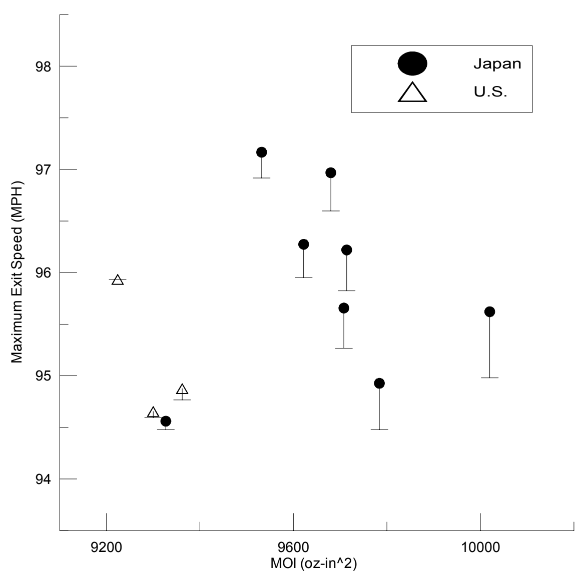

Fig. 7 Maximum exit speed distribution about MOI and performance change due to MOI normalization.

For the baseline MOI value to be used for calculating the MOI difference, the lowest MOI of the eleven MOI values was chosen. Because the changes in velocities were small, it was assumed that the BESR essentially did not change with change in swing speed. The error bars in Fig. 7 show the decrease in performance due to MOI normalization. The Japanese bats did not show significant difference in ball exit speed performance from the U.S. bats. However, some Japanese bats still outperform the "best" U.S. bat regardless of MOI normalization.

CONCLUSION

In this study, the performance of three U.S. and eight Japanese aluminum bats, which satisfy the respective protocols established in both countries, were compared. The supplementary tests and comparisons were performed to investigate if any correlation exists between static testing and dynamic performance. The performance test results showed that four of the eight Japanese bats tested outperformed all three of the U.S. bats. However, the other four Japanese bats performed within the BESR limit—similar to the U.S. bats. The barrel compression test results showed a clear trend that all the Japanese bats had offset loads of more than 7500 N, and all the U.S. bats had offset loads of less than 7500 N. The MOI comparison showed that most of the Japanese bats had higher MOI than the U.S. bats but performed similarly to the U.S. bats after correcting for the effect due to MOI increase.

Considering the results, it appears that the Japanese test protocol is regulating the performance of aluminum bats fairly well though there is no direct restriction on batted-ball-exit-speed performance.

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