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Nondestructive Testing Detects Altered Baseball Bats

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Corked Wood Baseball Bats

The history of the game of baseball is peppered with interesting stories of attempts to break the rules. Managers have been caught stealing signs; groundskeepers have altered the playing conditions of the field to the advantage of the home team; pitchers have used petroleum jelly, mud, emery boards, or thumbtacks to alter the surface of the baseball; and Major League Baseball players like Albert Belle, Norm Cash, Graig Nettles, and Sammy Sosa, have used corked bats.[1,4]

Major League Baseball rules dictate that a bat must be made from a solid piece of wood. A corked bat has a hole drilled into the barrel that is about 1 in. (25 mm) in diameter and about 8-10 in. (0.20-0.25 m) deep. The hole is filled with tightly packed cork or rubber superballs and capped with a wooden plug sanded and painted to disguise its presence.

The prevalence of corked bats in Major League Baseball is not known because players are caught only when the doctored bat breaks, revealing the cork interior. For example, in 1974, New York Yankees' Graig Nettles shattered his bat, sending several superballs bouncing around home plate. In 1987, Houston Astros outfielder Billy Hatcher's bat broke and one of the pieces ended up in the hands of Chicago Cubs third baseman Keith Moreland, who promptly showed the exposed cork filling to the nearby umpire. The most recent example occurred on June 3, 2003 when the bat swung by Chicago Cubs centerfielder Sammy Sosa shattered and the umpire who picked up the barrel fragment saw the exposed cork filling.

A physics analysis of the bat-ball collision concludes that corking a bat does not provide any performance advantage to a hitter,[2] but cannot determine whether or not a wood bat has been corked. There are, however, several nondestructive methods for detecting corked bats.

X-rays and CT scans. Pete Rose was frequently accused of using corked bats during his 1985 chase of the all-time hits record, but no broken bats ever exposed cork. Several of Rose's bats from 1985 are now in private collections. Recent X-ray scans of two of these bats show that they were indeed corked.[3]

Following the Sosa corked bat incident in 2003, the Major League Baseball commissioner's office ordered that X-ray scans be taken of the rest of Sosa's bats, including several that had been sent to the Baseball Hall of Fame after the 1998 home run record breaking season. The X-rays of all 76 of Sosa's other bats came back negative; the bat that broke during the 2003 game was the only one found to have been corked.

Sosa's 2003 corked bat fragment was eventually purchased by Grant DePorter, CEO of the Harry Caray Restaurant Group, and a doctor friend used computed tomography (CT) to scan the bat.[4] The CT scan images in Fig. 1, clearly show the

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hole filled with cork as well as the mismatch in the grain between the barrel and the wood plug used to fill the hole.

In August of 1987, just weeks before the Billy Hatcher incident, Major League Baseball commissioner Peter Ueberroth had asked experts at the National Institute of Standards and Technology to perform a quick study of several nondestructive methods for detecting the presence of illegal cork in a hollowed out wood bat.[5] The study found that CT scans provided the clearest image quality and were the best at detecting corking. However, the study concluded that standard medical X-ray scans were the quickest and most practical, especially since many professional ball parks have in-house X-ray machines for diagnosing player injuries.

Ultrasonic Scanning. The 1987 NIST study also explored ultrasonic tests, but found that it was difficult to conclude

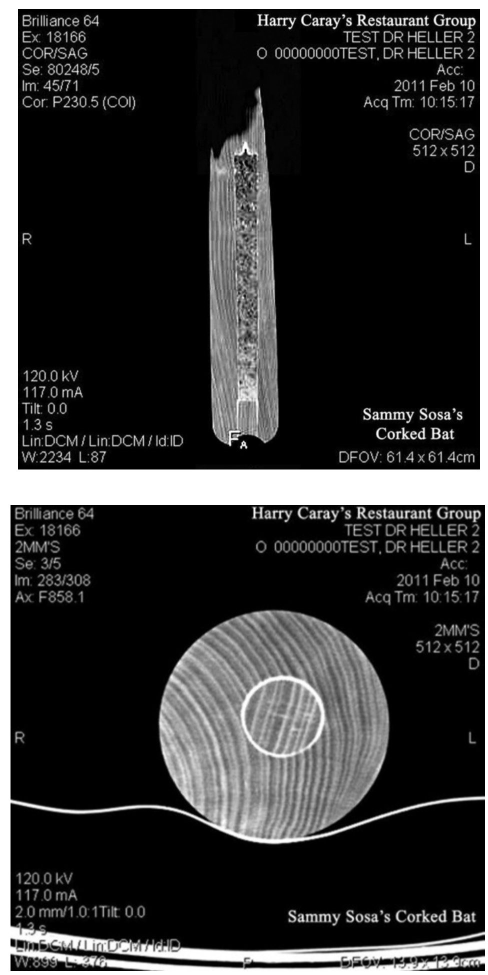

Figure 1. Computed tomography (CT) images of corked bat used in 2003 by Sammy Sosa: (a) side view of bat fragment and (b) end view of bat showing wooden plug. Reprinted with permission of Dr. Richard Heller and Harry Caray Restaurant Group.

with certainty whether a specific reflected signal was due to the presence of cork or the imperfections in the wood grain. However, a recently published study used a pair of 100 kHz narrow-band contact transducers (receiver and source) to measure the signal strength transmitted through three 4 in. (102 mm) thick blocks of sample wood: with and without cork filled holes.[6] The signal transmitted through the hollow block suffered an attenuation of 15.2 dB compared to the solid block. The corked block resulted in 9.6 dB of attenuation. Clean signals require a layer of liquid between the transducer and the bat barrel surface, something prohibited by Major League Baseball rules. The device has not yet been brought to market, but the technique shows promise.

Doctored Metal And Composite Softball Bats

The problem of illegally altering wood bats in Major League Baseball is certainly newsworthy when it happens, but it does not occur with great regularity. The opposite is true in amateur slow-pitch softball, where the illegal modification of bats is much more prevalent but does not often make the news.[7] The bats used for men's amateur slow-pitch softball are manufactured almost exclusively from aluminum or composite materials, and the barrels of these bats are hollow. The collision between a softball and a hollow bat barrel gives rise to the so-called *trampoline effect* in which the hollow barrel compresses as a spring, temporarily storing the energy from the collision and then returning almost all of that energy to the ball as the barrel elastically recoils to its original shape.[8] Careful design of the barrel wall thickness and material properties allows the trampoline effect to be tuned, maximizing the efficiency of the bat-ball collision to the extent that hollow aluminum and composite bats can be designed to produce batted-ball speeds that are significantly faster than are possible with a solid wood bat.

Governing bodies, such as the Amateur Softball Association or the United States Specialty Sports Association have implemented performance standards to regulate bat performance either by placing an upper limit on the batted-ball speed or by limiting the coefficient of restitution between bat and ball. Bat performance is measured following an ASTM test protocol[9] which fires balls at approximately 150 mph (240 km/h) toward a stationary bat and uses measurements of the bat and ball speeds before and after the collision to determine the coefficient of restitution of the bat. Knowledge of the inertial properties of the bat allows for calculation of the batted ball speed. Measurement of bat performance in the laboratory is time intensive and expensive, and requires specialized ball cannons, light gates, bat pivot devices, and computer hardware for data collection and processing.[10]

Almost as soon as bat performance standards for softball were adopted, players discovered that they could significantly improve the performance of a bat by modifying it to increase the trampoline effect. So-called *bat doctors* sprang up around the country, offering to cleverly repaint banned high-performance bats, add or remove mass in the barrel or handle of the bat to change the swing weight (moment-of-inertia), or the more drastic modification of removing the end-cap and using a lathe to shave the inner wall of the barrel.[11] Governing bodies have imposed heavy penalties and fines against players caught using illegally altered bats, but the detection of altered bats in the field of play has presented a challenge.

While X-ray machines may exist in most Major League Baseball stadiums, they certainly do not exist in a portable form at the thousands of amateur softball parks across the country. Even if they were available, X-ray scans could not be used to detect the modification of aluminum bats, and X-ray scans would not easily detect evidence of shaving in a thin-walled hollow composite bat.

Ultrasonic measurement techniques would seem to be the preferred method for detecting alterations in hollow softball bats since ultrasonic sensors are frequently used to measure the thickness of hollow metal, plastic and composite pipes. However, knowing the barrel wall thickness would detect modification only if one knew the original wall thickness and manufacturers are unwilling to make this information publically available. Reflections from the air gaps between the thin layers of a double-walled aluminum bat, or from the different layers of composite and resin in multi-walled composite bats could lead to errors in thickness measurements.

The difficulty in detecting illegally altered softball bats is exacerbated by the fact that it is possible to improve the performance of a composite bat without actually changing the thickness of the barrel walls. A currently popular technique for improving the performance of a composite bat is to use one of several accelerated break-in methods.[12] It is well known that the performance of composite bats improves with use as the layers of composite materials gradually delaminate with use and the bat wall softens, increasing the trampoline effect. A quick search of the web will reveal a small industry for rolling and pressing bats to accelerate the break-in process. Awareness of this phenomenon led the Amateur Softball Association to begin rolling bats prior to certification testing for compliance with their performance standard, and also caused the National College Athletics Association in 2009 to ban composite bats from use in college baseball after a large number of certified composite bats were found to exceed performance standards when tested following the College World Series that year. However, approximate estimates of performance may be obtained

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indirectly from vibration frequencies and stiffness values.

Hoop Frequency. A hollow softball or baseball bat exhibits a number of vibrational modes involving radial oscillations of the cylindrical barrel. The fundamental mode shape with the lowest frequency is termed the *hoop-mode* of the bat. Modeling this vibrational hoop mode using a simple mass-spring approach captures the essential physics of the bat-ball collision.[8] Experimental results for softball and baseball bats have shown that the frequency of this hoop mode may be used as a fairly accurate predictor of the performance of a bat.[13,14] Figure 2 shows the measured batted-ball speeds for a variety of aluminum single-walled and double-walled, titanium, and composite softball bats plotted as a function of the hoop mode frequency. The data shows that bats with lower hoop frequencies tend to produce higher batted-ball speeds. The Amateur Softball Association requires that the laboratory measured batted-ball speed fall below 98-mph, suggesting that a bat with a hoop frequency lower than 1300 Hz would exceed this performance limit.

The hoop mode frequencies in Fig. 2 were obtained through experimental modal analysis, a test procedure in which a hammer with an instrumented force gage provides an impulse to the barrel of the bat and the resulting vibration response is measured with an accelerometer. The frequency response function (the ratio of acceleration to force as a function of frequency) for a combination of impact and measurement locations along the length of the bat may be used to obtain the vibrational mode shapes, corresponding natural frequencies, and damping rates by curve fitting the data with modal analysis software. A typical setup for measuring the vibrational response of a softball bat includes power supplies for hammer and accelerometer as well as a two-channel analyzer to capture the frequency response function. While suitable for laboratory testing, this experimental setup is not conducive to field tests.

An ongoing project hopes to develop a hand-held device to measure the frequency of the hoop mode using a microphone and a programmable dedicated microchip to sample, filter and process the signal, and compare the measured frequency to a reference value. Such a device would not be able to detect whether a bat had been illegally modified, but it

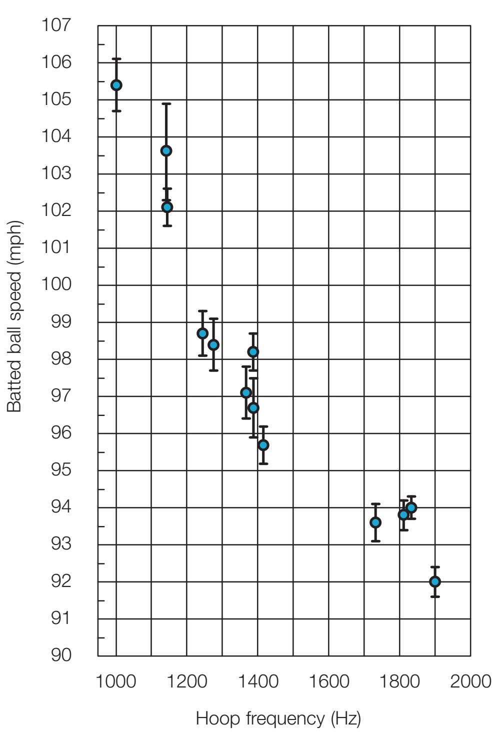

Figure 2. Batted-ball speeds for collection of softball bats showing increases in performance as hoop frequency decreases.

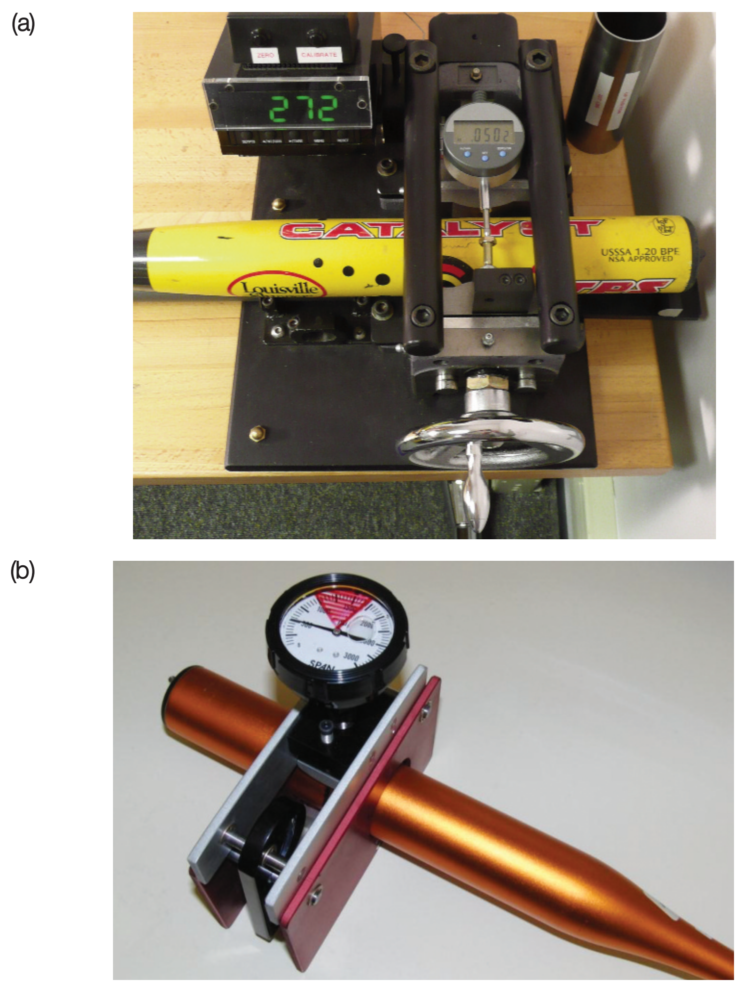

Figure 3. Barrel compression testers measure barrel stiffness of hollow composite or aluminum softball bats: (a) setup for laboratory testing and (b) portable device.

could predict whether or not the bat might exceed the required performance limits.

Barrel Stiffness. Another approach to measuring the elastic *springiness* of a hollow bat barrel involves the static stiffness of the barrel. Experimental data relating performance to barrel stiffness, as measured using a compression tester in the laboratory, follows a trend similar to that shown in Fig. 2; lower values of barrel stiffness result in higher batted-ball speeds. In 2004, the Sporting Goods and Manufacturing Association commissioned the portable barrel compression tester for field use (Fig. 3a). The force in pounds required to compress the barrel by 0.05 in. (1.27 mm) is used to calculate the barrel stiffness. This device was used to police bats at a 2004 national slow-pitch softball tournament sponsored by the United States Specialty Sports Association. Five hundred bats were tested and 75 bats were removed from play due to excessively low stiffness values.

A more portable (requiring no electricity) and simpler to use barrel compression tester was recently developed by the Sports Science Lab at Washington State University (Fig. 3b). Bats for which the pressure gage reading falls in the red zone are not stiff enough to be legal. The stiffness values from this portable tester do not completely correlate to values measured in the laboratory with a compression tester, but a portable tester like this could indicate whether a bat might be suspect of having been tampered with, or at least whether it might exceed performance limits.

Further research in these areas is ongoing. Available data suggests the correlation between performance and laboratory measurements of hoop frequency or barrel stiffness for specific softball bats that are known to have been altered is not yet close enough for reliable field detection of illegally altered bats using portable devices in the field, but results are encouraging.[15]

Conclusion

Nondestructive test methods may be used to detect baseball and softball bats that have been illegally altered. X-ray scans and ultrasonic testing can easily detect corking in a wood bat. Measurements of the hoop frequency of barrel vibrations and/or the static stiffness of the barrel can identify hollow aluminum and composite softball bats that may exceed performance limits due to illegal modification.

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