Describing the Performance of Cricket Bats and Balls

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Nomenclature:

BBS	Batted-ball speed
DS	Dynamic stiffness
m_b	Cricket ball mass
F_p	Peak impact force
v_i	Inbound ball speed
e_a	Collision efficiency
v_b	Cricket bat speed
v_p	Cricket ball speed
MOI	Moment of inertia
Q	Impact location on the cricket bat
COR	Coefficient of restitution

ABSTRACT:

The aim of this study was to describe the performance of cricket bats and balls. An experimental test apparatus was developed to measure the performance of cricket bats and balls under dynamic impact conditions representative of play. Experiments were carried out to measure the elasticity and hardness of the cricket balls as the function of incoming speed. It was observed that the ball coefficient of restitution and hardness of seam impacts was 1.1% and 1.6% higher than face impacts, respectively. A bat performance measure was derived in terms of an ideal batted-ball speed based on play conditions. Bat performance was compared before and after knock-in (a common treatment to new cricket bats) which decreased 0.24%. Wood species had a relatively small effect where the performance of English willow bats was on average 0.84% higher than Kashmir willow bats. A composite skin, applied to the back of some bats, was observed to increase performance by 1.4%. While the different treatments and designs had a measurable effect on performance, they were much smaller than the 10% difference observed between solid wood and hollow baseball and softball bats.

Keywords: Cricket bat, Cricket ball, COR, Dynamic stiffness, BBS

Introduction

Although, the sport of Cricket is 500 years old [1] there has been little scientific research done to study the bat or the ball. Since the 17th century the cricket bat has been changed various times, but must be made of solid wood [2]. The main aim of the bat is to send the ball to its home by playing the most powerful shot, and minimizing shock to the batsman's hand. The blade is made of English or Kashmir willow which is strong, lightweight and has good shock resistance. The handle is made of cane which has good shock absorbing properties. The length of the bat cannot exceed 38 inches (96.5 cm) and the width of the blade must be less than 4.25 inches (10.8 cm) [2].

Before playing in the field the bat is usually "knocked-in". Knock-in is a process of squeezing the fibers on the surface of the bat by repeated hitting with a wooden bat mallet or old ball for 2 to 6 hours. The treatment increases the surface hardness of the blade, which can double in some cases [3]. Knock-in has been shown to compress the wood fiber near the surface, producing a stiff and dense region that affects the flexural stiffness and vibration of the bat [4]. Little has been done, however, to consider the effect of knock-in or wood species on performance.

The performance of cricket bats has been compared using their coefficient of restitution (COR); defined as the ratio of the relative speed of the objects after and before the collision. One study found that the COR of the bat decreased as the bat stiffness increased [5]. Recent advances in technology and materials have motivated a number of changes in cricket bat design. While some studies suggest these advances have not affected performance, more work is needed to quantify their contribution [6].

Cricket balls are made from a cork nucleus with layers of wound wool and cork and a leather cover. The leather exterior is usually constructed from four sewn pieces. A cricket ball weighs between 5.5 to 5.75 ounces (155.9 to 163 g) and can be no more than 9 in (22.9 cm) in circumference [2]. Cricket balls are made in a number of different ways, with varying core design. There is little information on the effect of cricket ball properties on bat performance. One study showed that greater deformation was found for impacts landing on the seam, compared to those landing perpendicular to the seam [7].

EXPERIMENTAL

The Ball Test Equipment:

Some have found that quasi-static tests provide an unreliable measure of sports ball response under dynamic conditions [8]. Accordingly, an apparatus was developed to dynamically characterize cricket balls. The apparatus consisted of an air cannon and a rigidly mounted load cell, as depicted in Fig. 1. Light gates were placed between the cannon and load cell to measure the in-bound and rebound ball speeds.

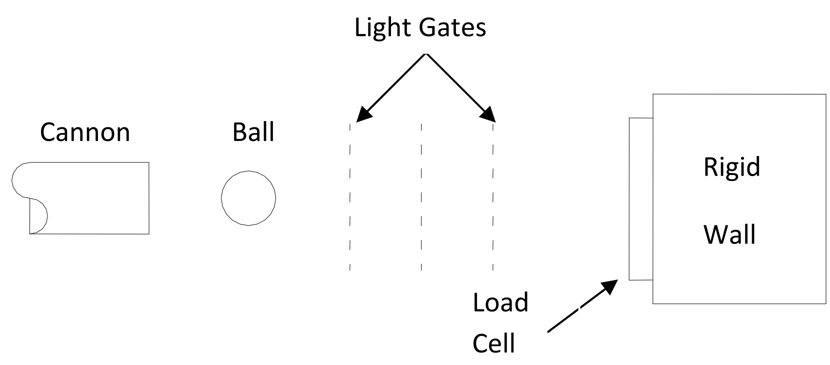

Figure: 1 Experimental Setup for COR and Dynamic Compression.

Ball Testing:

Cricket balls were compared by their elasticity and hardness. Elasticity was quantified through their rigid wall COR. Ball hardness was quantified through a so-called dynamic stiffness [9]. This was defined by equating the ball's initial kinetic energy with its stored energy upon impact with the load cell. The unknown ball displacement was replaced by the measured force, assuming the ball acted as a linear spring. Accordingly, an expression for the ball's dynamic stiffness, DS, may be found as

$$DS = \frac{1}{m_b}\left(\frac{F_p}{v_i}\right)^2 \tag{1}$$

where m_b is the ball mass, F_p is the peak impact force, and v_i is the inbound ball speed.

In the current study balls from two manufactures were used. The balls were conditioned at 72 ± 2° F and 50 ± 5% relative humidity for 14 days prior to testing. Figure 2 shows ball dynamic stiffness as a function of incoming ball speed. On average, the dynamic stiffness of ball model A was 30% higher than model B. The DS increases with speed, suggesting the ball behaves as a non-linear spring.

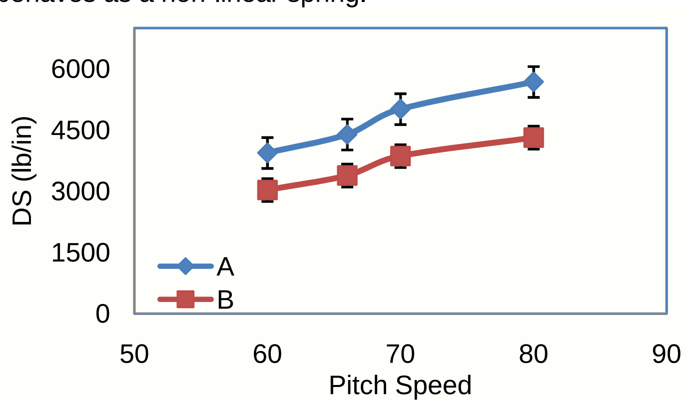

Figure: 2 Dynamic stiffness as a function of incoming ball speed for two ball models

Figure 3 shows the COR of the two ball models as a function of speed. Both models show the characteristic decrease in COR with increasing speed. The average COR values are much closer than the dynamic stiffness, where model A was 2% higher than B.

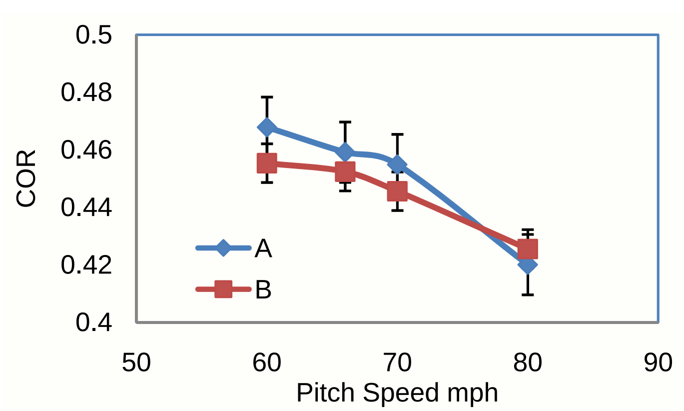

Figure: 3 Average COR Vs Pitch Speed mph

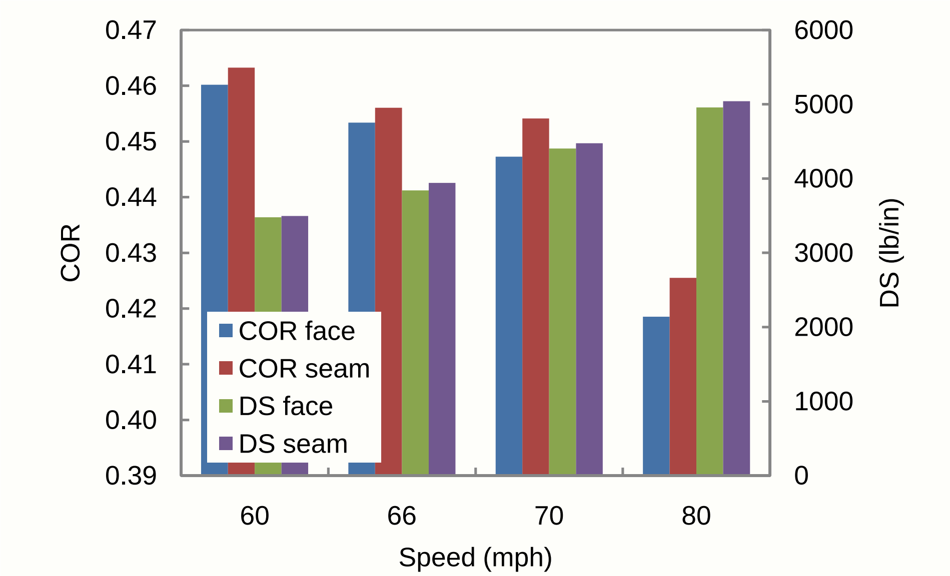

Figure: 4 Comparison of COR and DS at Face and seam impact

Cricket balls have a pronounced seem that may produce a different response than the face. To consider this difference, seem and face impacts are compared in Fig. 4. On average, seem impacts were observed on have a 1.1% higher COR and a 1.6% higher DS than face impacts.

Figure 5 shows the force-displacement curve of two representative balls of model A and B. Displacement was obtained by dividing the force by the ball mass and integrating twice. It was observed that ball A had 17% more deformation than B. The cross section of ball A and B are compared in Fig. 6. The construction of ball B was more uniform than ball A, which may affect repeatability. The standard deviation of the COR and dynamic stiffness was 56% and 35% higher, respectively, for ball A, for instance. The uniformity of ball B may have been achieved by its molded rubber core. Ball A has a solid cork core which was only approximately spherical. The different ball constructions and materials likely contribute to the characteristic responses observed in Fig. 5

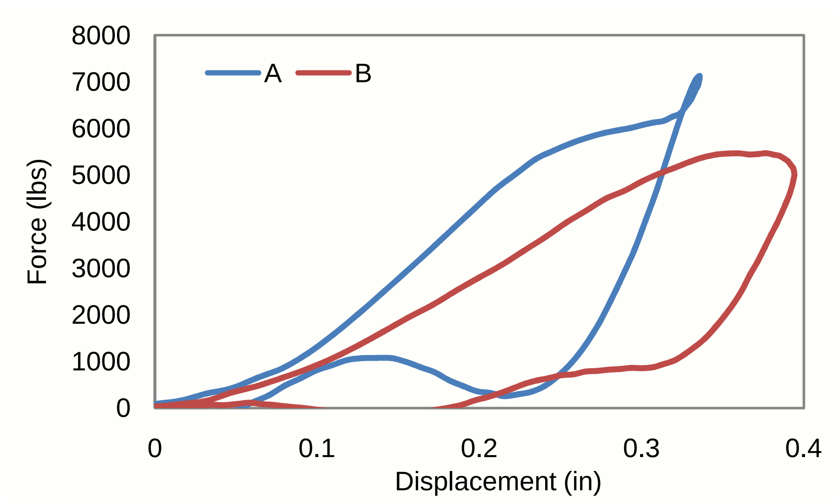

Figure: 5 Representative force-displacement curves for two ball models.

Figure: 6 Cross Sectional View of Cricket ball A and B

Bat Testing Equipment:

The bats were tested using a fixture similar to the ball test as shown in Fig. 7. The principle difference between the bat and ball test was the rigid wall was replaced by a pivot that allowed the bat to recoil after impact and controlled the impact location. In the bat tests an incoming ball speed of 60 mph was used to prevent accumulated bat damage from influencing the results.

Light gates measured the ball speed before and after impact. The ratio of the rebound to inbound ball speed is the so-called collision efficiency, e_a [10]. If the bat, v_b, and ball, v_p, speed in play conditions are known, the collision efficiency may be used to find the batted ball speed, *BBS*, according to

$$BBS = e_a v_p + (1 + e_a) v_b \tag{2}$$

The bowled ball speed is relatively easy to measure in play and is usually taken as a constant when comparing bat performance. The release speed of fast bowlers approaches 100 mph at the hand, while the speed at the bat after impacting the pitch is near 80 mph [11]. In this work it was taken as 85 mph. The bat speed is more difficult to measure and has a greater effect on the BBS. For this work a bat speed of 70 mph, 21 inches from the knob end was used. (This bat speed was found by considering a ball flight trajectory of 450 yards.) Bat speed is not constant, but will vary with MOI and impact location, *Q*, [12], [13]. The following was used to account for these effects

$$v_b = 70\left(\frac{Q}{21}\right)\left(\frac{10{,}000}{MOI}\right)^{1/4} \tag{3}$$

Each bat was impacted six times at multiple locations along its length until a maximum BBS location was found within 0.50 inches. A representative bat performance curve is shown in Fig. 8. Note the relatively small region which produces an optimum BBS.

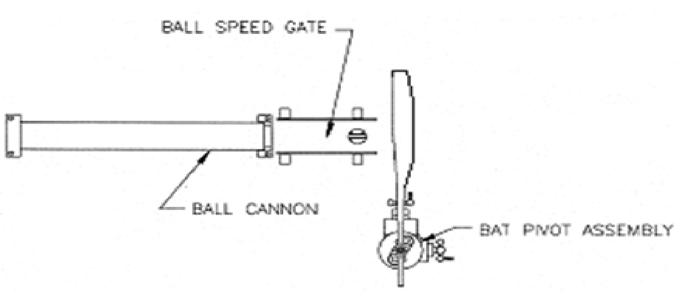

Figure: 7 Schematic of test fixture used to test cricket bats.

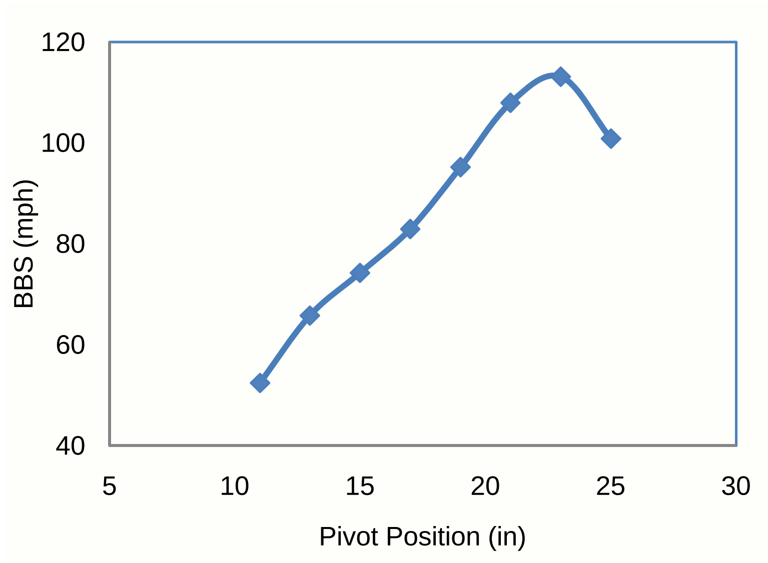

Figure: 8 Representative bat performance curve.

Bat Testing

The surface of the blade is commonly knocked-in and oiled to make the bat more durable. To consider the effect of knock-in on performance, the bats listed in Table 1 were tested before and after knock-in. As shown in Fig.9, knock-in was observed to have a relatively small effect on performance, decreasing it by 0.25%.

Table 1 Properties of bats used in the performance comparison.

Bat code	Process	Material	Length (in)	Weight (oz)	MOI (oz in^2)
Bat 1	Unknocked	Kashmir Willow	33.6	41.2	11227
	Knocked and oiled		33.6	41.3	11258
Bat 2	Unknocked	Kashmir Willow	33.8	40.4	11638
	Knocked and oiled		33.8	40.5	11617
Bat 3	Unknocked	English Willow	33.4	37.7	9799
	Knocked and oiled		33.4	37.5	9774
Bat 4	Unknocked	English Willow	34.9	39.5	11779
	Knocked and oiled		34.9	39.5	11801
Bat 5	With Composite	Composite skin	33.8	38.3	10703
	Without Composite		33.8	36.8	10216

The blade of most cricket bats is made of either Kashmir or English willow. Many view English willow as superior, for which a premium price is usually paid. The average performance of two English and Kashmir willow bats is compared in Fig. 9, where the performance of English willow was observed to be 0.84% higher than Kashmir willow.

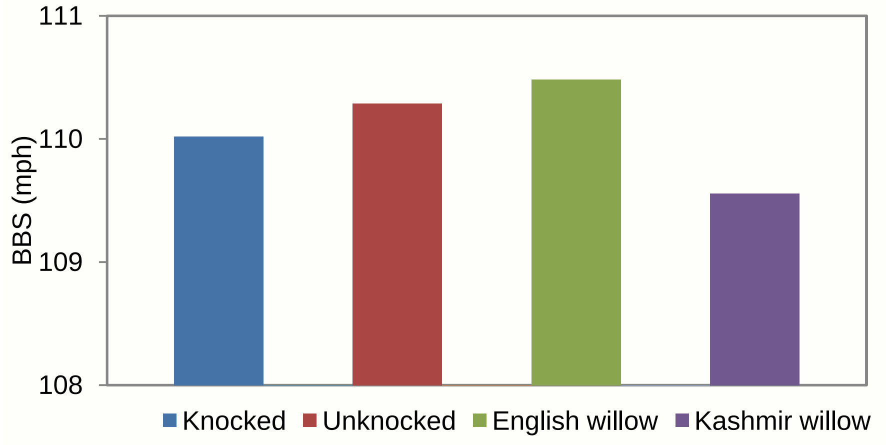

Figure: 9 Average performance between knocked, un-knocked, English willow and Kashmir willow

While Cricket rules require the bat to be made of wood, some manufacturers have added a thin composite skin to the back surface. The skin stiffens the blade and is purported to improve durability. The performance of a bat was compared with and without the composite. The results are included in Fig 10, which shows the skin increased the BBS by 1.44%. It should be noted that removing the skin reduced the bat's MOI by 4.6%. The effect of MOI on bat performance, independent of the composite skin, may be considered in Eq. (2) by holding the bat-ball COR constant and changing the bat MOI. Accordingly, a 4.5% increase in MOI was found to increase bat performance by 0.85%. Thus, roughly half of the performance advantage attributed to a composite reinforced blade is due to its mass.

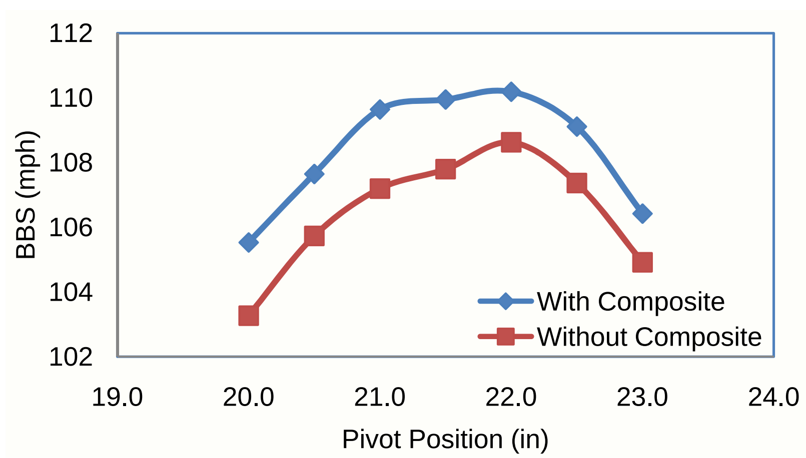

Figure: 10 Comparison of cricket bat with and without composite skin.

Summary:

This study considered the performance of cricket bats and balls. A test apparatus to measure bat and ball properties at impact speeds representative of play conditions was shown to have utility in comparing bat and ball response. It was found that a cricket ball impacted on the seam had a 1.1% and 1.6% higher COR and dynamic stiffness, respectively, than face impacts. It was also observed that the construction of cricket balls can differ significantly. These differences were observed to have a measurable effect on the ball response and repeatability. The knock-in process and willow species were found to have a relatively small effect on performance of less than 1%. The contribution of a reinforcing composite skin to the back surface of the bat was also relatively small (1.4%), although larger than the effect of knock-in or willow species.

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