Improving the performance of cricket bats: An experimental and modelling approach

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Abstract

The aim of the current research project was to characterise the difference in the sweet spot of a standard and modified (bat with pre-stressed wooden inserts) cricket bat, as utilised by amateur batsmen facing amateur bowlers. The project was divided into three parts, experimental, analytical analysis and finite element modelling. An experimental bat and ball test apparatus was developed to measure the difference in performance of a cricket bat with and without modifications. The outcomes of this work showed that the addition of a specified insert in the sides of a cricket bat can significantly improve a cricket bat's performance. The potential to use this type of insert could be employed in any design of bat to improve its performance without any additional modifications to the profile of the existing layout.

Keywords: Finite element modelling; Coefficient of restitution; Modified sports equipment

Introduction

Bat and ball sports such as tennis, baseball, golf and cricket have benefitted largely from improvements in technology. One area of interest to equipment designers and sports participants alike is the *sweet spot*. The sweet spot is the location on the racquet, bat, or club that performs the best. That is, the spot where the ball or projectile has the greatest rebound velocity.

Cricket is a bat-and-ball game; the dimensions and construction of the bat are stipulated by the Marylebone Cricket Club (MCC), which has been recognised as the sole authority for drawing up the governing rules of cricket (MCC, 1962; MCC, 2010). Cricket bat construction and utilisation are of prime concern to players, and experts have suggested nine major bat characteristics to be taken into account in the design of cricket bats, as shown in Table 1.

Bat performance can be assessed by various metrics including player comfort, the sweet spot, and modal vibration analysis. The sweet spot is associated with minimum discomfort to the batsmen and maximum ball rebound velocity. It has been defined as the impact point that minimises the impulse forces transmitted to the hands, where the position of this point is governed by the mass distribution of the bat and its moment of inertia (Brooks, Mather, & Knowles, 2006; Cross, 2004; Fisher et al., 2006).

Table 1
Design characteristics of cricket bats and definitions

Characteristic	Definition
The 'Sweet Spot.'	Point or area on a bat at which it makes most effective contact with the ball
Centre of Percussion (COP)	Impact point between the tip and the handle of the bat where there is no sudden motion of the handle
Coefficient of Restitution (COR)	The ratio of the bounce speed to the incident speed
Rigid Body Approximation	How physical properties such as mass, moment of inertia and balance point can affect ball rebound speed
Moment of Inertia	A measure of how difficult it is to change the rotational velocity of an object which is rotating about a pivot point (i.e. a cricket bat)
Collision Replication	What happens to a ball when it hits a bat
Bat Substitution	Comparing materials, from a mechanical perspective and from the structural perspective; can there be a substitute for the English willow?
Bat Vibration	A special spot on a bat where the shot feels best- the fundamental vibration node and the centre of percussion
Forces between Bat and Ball	Force on the ball which has to slow it down to a complete stop, and then accelerate it back in the other direction

Various modifications and designs have been developed using wood, aluminium and composite materials to improve the performance of baseball and cricket bats (Eftaxiopoulou, Narayanan, Dear, & Bull, 2011; Pang, Subic, & Takla, 2011; Shenoy, Smith, & Axtell, 2001; Smith, Shenoy, Axtell, & Sem, 2000; Sridharan, Rao, & Omkar, 2015). An alternate approach has been to modify the wooden bat with wooden side inserts, originally sourced from staves used in old wine barrels, developed by Ron Sears (Echuca Times, 2012) with a version being recently marketed (Slazenger, 2016). The wooden insert staves are flattened and twisted before being inserted into the sides of the bat, retaining their spring.

The current work examines the effect of these inserts on bat performance. Although inserts are not appropriate for first class matches, they are deemed suitable for junior and amateur level games, played by youth, novice, and developing players. Equipment scaling and modification is a common recommendation within junior sports to adjust equipment to the needs of the children. These modifications are indicated to enhance skill acquisition; and second, to increase the fun/motivation of the learner (Farrow & Reid, 2010).

In this work, a standard cricket bat, having dimensions accorded by the MCC was utilised for all the experimental, analytical and modelling work (Bower, 2012; Brooks et al., 2006; Cross, 2004; Grant, 1998; Gutaj, 2004; MCC, 2010; Wood & Dawson 1977).

Finite Element Modelling

Finite element analysis (FEA) was originally developed for solving solid mechanics problem that would not necessarily be possible with direct mathematical analysis where finding an exact solution is difficult. FEA simplifies a real engineering problem into a problem that can be solved using an approximate solution. The behaviour of bats has been modelled using FEA and then correlated with analytical approaches, and triangulated with a series of experimental tests (Symes, 2006). These approaches allow the effects of geometric alterations under different load conditions to be analysed. In a comprehensive study of the impact characteristic of sports balls and the performance of striking implements, Cross (2014), employed FEA models. Penrose and Hose (1998) utilized FEA techniques to assess the cricket bat-ball impact and so providing guidelines to bat manufacturers in the shaping of the bat to control its properties of flexibility and vibration. FEA was seen as a feasible method of calculating the behaviour of cricket bats, even for simplified models (John & Li, 2002). Ruggiero, Sherwood, Drane, Duffy, and Kretschmann (2014) employed FEA to develop calibrated models of the breaking of wood baseball bats in controlled lab conditions, and then explored how the bat profile influenced “bat durability and what potential changes can be made in bat profile to satisfy player desires while increasing bat durability” (p. 527).

In developing an finite element (FE) model for cricket bats and balls, James, Curtis, Allen, and Rippin (2012) established the validity of a rigid body model of the cricket ball-bat impact, whilst a finite element rigid body model was similarly developed for two bat geometries, with ball/bat impact simulations (Allen, Fauteux-Brault, James, & Curtis, 2014). Rigid body analysis has further been shown by Symes (2006) as an appropriate method of investigating bats (the rigid body) following object collision. This is relevant to the cricket bat and ball contact situation. A bat and cricket ball FE model was developed and validated against laboratory-based experimental ball testing.

Experimental Procedure

To measure the difference in performance of a cricket bat with and without pre-stressed wooden inserts, a specialized experimental test apparatus was developed. The dimensions of the bat were: blade length of 560mm; width of 108mm; and thickness of 59mm. Shown in Figure 1(a) is a schematic diagram of a cricket bat, alongside a schematic diagram of a bat with an insert, where a groove is made in the bat along both edges approximately 6mm in width by 480mm long. Depicted in Figure 1(b) is a cricket bat blade with an edge oak insert and in Figure 1(c) is a depiction of the 3D Solid Model of the cricket bat with edge inserts as created in Solidworks (Dassult Systèmes SolidWorks Corporation, Waltham, MA, USA).

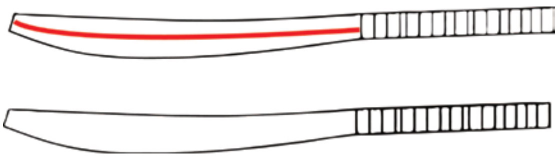

Figure 1(a). Schematic edge view of a cricket bat, alongside a schematic edge view of a bat with an insert (shown in red).

Figure 1(b). Cricket bat blade with an edge oak insert.

Oak insert

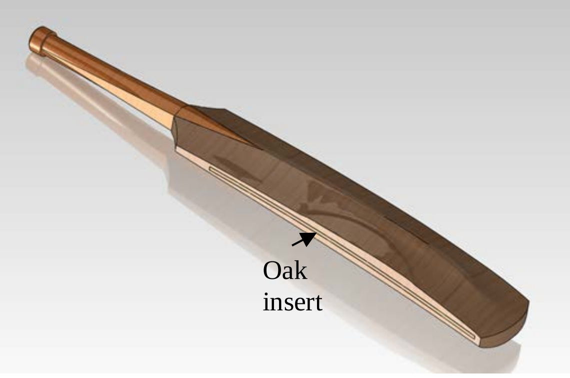

Figure 1(c). Depiction of the 3D Solid Model of the cricket bat with edge inserts created in Solidworks.

A schematic diagram showing the spring loaded ball launching apparatus is shown in Figure 2(a). It was designed to allow a consistent velocity output, accurate ball impact location, and ball orientation with no spin on the ball. Shown in Figure 2(b) is the experimental arrangement of the cricket bat; handle clamps, load cells, support frame and milling table as well as the ball launching device. The milling table allowed the bat to be moved to precise impact locations on the cricket bat. The cricket ball used in Australia's domestic competition below first class cricket level is the Kookaburra Regulation Ball (Fuss, 2008). Cricket balls used in our work are composed of a two-piece leather case ball, tension machined wound, with bonded cork and rubber core. The cricket ball measures between 22.4 and 22.9 cm in circumference and weighs between 155.9 and 163 grams.

Figure 2(a). Schematic diagram showing the spring loaded ball launching apparatus.

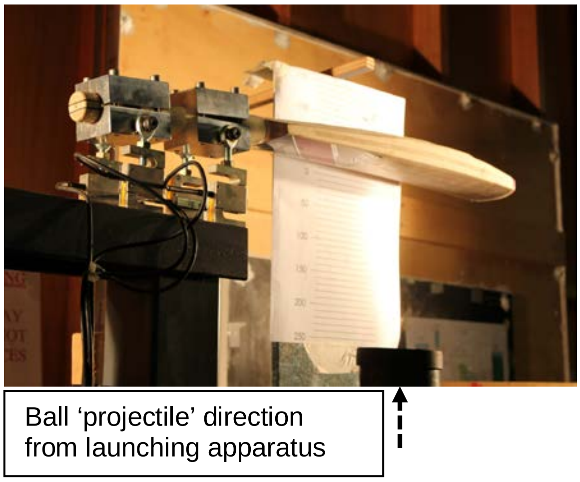

Figure 2(b). Experimental setup.

The experimental apparatus consisted of a ball launching machine, load cells, rigid wall, laptop computer with a National Instruments 9237 analogue bridge input module and Phantom V210 high-speed camera. The ball launching machine consisted of a vertical 100NB pipe, two 30 N/mm compression springs (free length 250mm), a Wichard quick release shackle and a brake type winch. The desired ball velocity was achieved by compressing the spring a set distance using the viewing slot on the side of the vertical pipe. This experimental approach allowed an accurate and repeatable inbound velocity to be achieved.

The blade bending stiffness was performed in an Instron 5500r dual column material compression/tension machine. The objective of the work was to measure the coefficient of restitution (COR) and the dynamic stiffness of the cricket ball that would be used to validate the dynamic material properties used in the numeric model (Bower, 2012; Carre, James, & Haake, 2004; Cross, 1998, 2004). The cricket bats were placed over two supports shaped to the contours of the bat, designed to minimize any damage to the surface of the bats. The measurement of the spring rate was performed on the same Instron 5500R material testing machine using a 3-point bending technique. The stiffness, Young's Modulus and the spring rate were determined from the same test. The cricket bats were rigidly held using specially designed clamps arranged in two positions on the handle (top and bottom hand positions) 130mm apart. A set of four, 100kg S type loads cells (designed for tensile and compressive forces) were used in conjunction with rod ends so that no bending moments were transmitted through them.

Numerical Modelling

The Cricket Ball

Researchers have demonstrated that rigid body models can aid in the evaluation of the effects of cricket bat modification on bat performance, specifically for parameters such as ball rebound speed (Goodwill & Haake, 2000; James et al., 2012). The cricket ball impact with a rigid wall was modelled using ANSYS/LS-DYNA Version (ANSYS, 2011). The cricket ball was modelled as a homogeneous sphere (Latchman & Pooransingh, 2015), 71.6mm in diameter, with a mass of 156g, a density 851kg/m3 and isotropic properties. The dynamic finite element method can be performed using either explicit or implicit time integration method. An explicit method was used for this study, which assumes a linear change in displacement over each time step. A viscoelastic material in LS-DYNA called the Power Law Model, consisting of 4321 SOLID 164 – 8 noded solid elements was selected for the cricket ball. The material is defined by a constant bulk modulus, k and a time-dependent shear modulus G(t);

$$G(t) = G_\infty + (G_0 - G_\infty) \cdot e^{\beta t}$$

Where G_∞ is the long-term shear modulus, G_0 is the instantaneous shear modulus, t is the time and β is the decay constant that determines how quickly the shear modulus changes between the two values.

The SOLID-164 elements are used for three-dimensional modelling of solid structures. The elements are defined by eight nodes having the following degrees of freedom at each node: translation, velocities, and accelerations in the x, y, and z directions (used in explicit dynamics analysis only).

The initial values for the Power Law Model were based on those developed by Smith and Singh (2008). The simulation was run using these values and the results compared to gain confidence in the model setup in ANSYS/ LS-DYNA. Once this was established the model was tuned to our experimental cricket ball data (COR and the force vs. time data). A surface to surface contact was used between the cricket ball and the rigid steel plate to prevent penetration during impact. An initial velocity of 14.3 m/s was applied to all the nodes of the cricket ball model.

A fine FE mesh was used to establish the convergence for the cricket ball and consisted of 110821 elements, depicted in Figure 3. The rigid plate was modelled with the properties of steel using 15129, 8-noded solid elements (SOLID164) with dimensions of 100mm x 100mm x 25mm. The model of the rigid wall impact was tuned until the characteristics of the force vs. time curve were comparable. A comparison of experimental and FE simulation of ball velocity is shown in Figure 4.

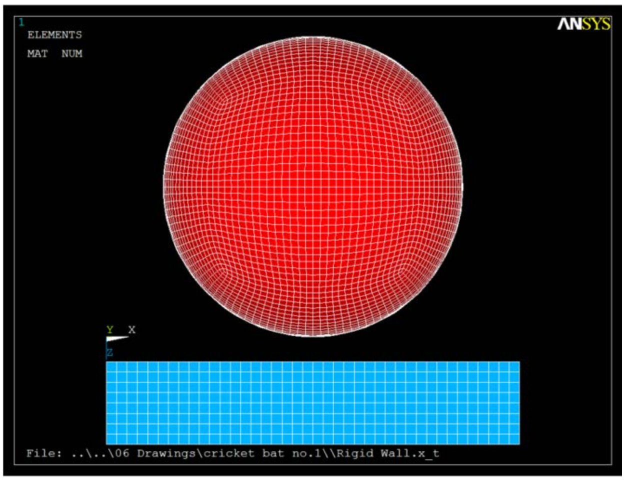

Figure 3. FE Mesh of a cricket ball.

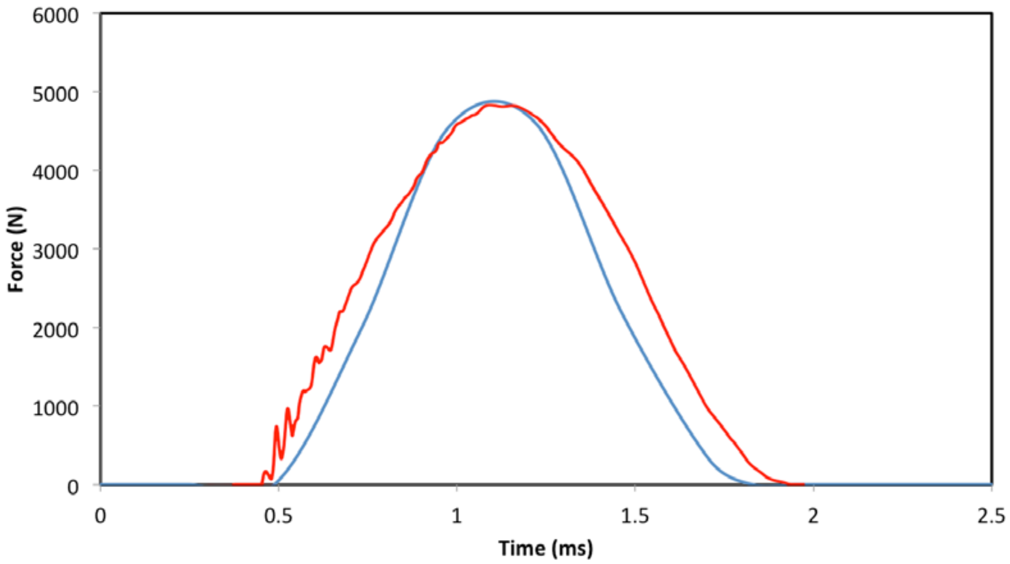

Figure 4. Comparison of experimental and FEA simulation for dynamic ball impact forces (50 km/hr). Experimental (Blue) and FEA Simulation (Red).

The Cricket Bat

The cricket bats supplied had a complex 3D geometry, with varying cross sections along the length of the blade. Pang et al. (2011) developed an FE model investigating the strength of a Polycarbonate-foam sandwich against impact by a cricket ball. The methodology may be applied to any form of material used for bat construction and ball impact. In our work, the characteristics of the bat are shown in Figure 5, where the ball strikes at location ‘B’, 355mm from Point A and 45mm from the centre of mass. One side of the cricket bat was modified to reduce the edge thickness for two reasons; to show that a cricket bats weight could be reduced without reducing performance with the oak timber inserts and to magnify the increase in performance at low experimental velocities (which may be appropriate for simulation “slow” bowling). A 3D FE mesh model of the cricket bat is shown in Figure 6. The experimental data was used to improve the accuracy of the computer simulation, adjusting input parameters for the material properties until a satisfactory result was achieved.

Results and Discussion

Bat Results

The right side of the profile of the bat has been modified, by the addition of a timber insert. The left side of the bat has a reduced edge thickness from a maximum of 34mm to 29mm to try and show the potential improvement at low ball velocities.

Each bat was impacted three times at approximately 31, 41and 51 km/hr. The average of the three speed measurements vs. distance along the blade from the toe of the bat was plotted. Measurements were taken on the centreline and 35mm either side of the centreline.

The experimental results show that at the sweet spot, or peak output velocity, the improvement in the output or rebound velocity of the bat-ball combination increases by an average of 22%. Even taking into account the accuracy of our measurements and the number of test points taken the percentage improvement would be between 17% and 27%. The results of the forces and loads for the batsman’s hand (compressive forces on the bottom hand, as well as tensile forces for the top hand) did not significantly change. However, the torsional data indicates a reduction in torsional loads for the bottom hand with the insert.

Results from the modelling, shown in Figure 7, indicate an improvement in performance (ball rebound velocity) over the length of the bat tested at increasing ball inbound velocity. The inclusion of an insert shows an increase in bat performance on the left-hand side of the bat (where the insert was located).

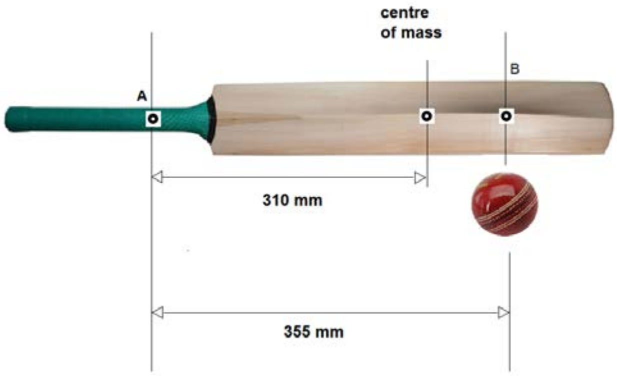

Figure 5. Bat characteristics.

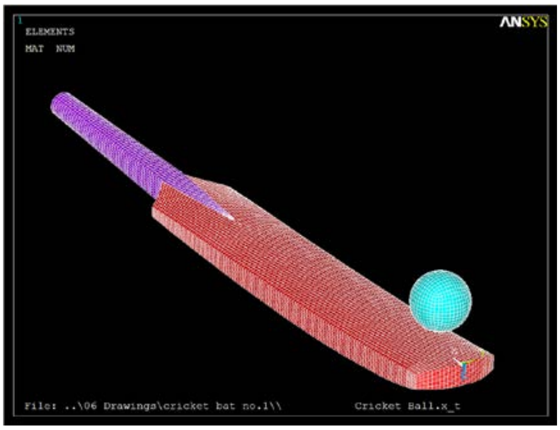

Figure 6. FEA mesh cricket bat model.

Bat Centre

The centreline of the bat shows no change in performance due to the insert. The influence of the inserts seems to be limited to the edges where the thickness is reduced.

Bat Right Side

The right side of the profile of the bat has not been modified. The results for the right-hand side are similar to the centre of the bat. The impact forces at the velocities the test were done at showed no improvement in the rebound of the ball. This result does not necessarily imply that at higher inbound velocities will result in no improvement in bat performance. Further testing at various inbound ball velocities is required to characterize the bat performance. The force data on the right-hand side shows about a 5-10% reduction in loads for the top and bottom hands.

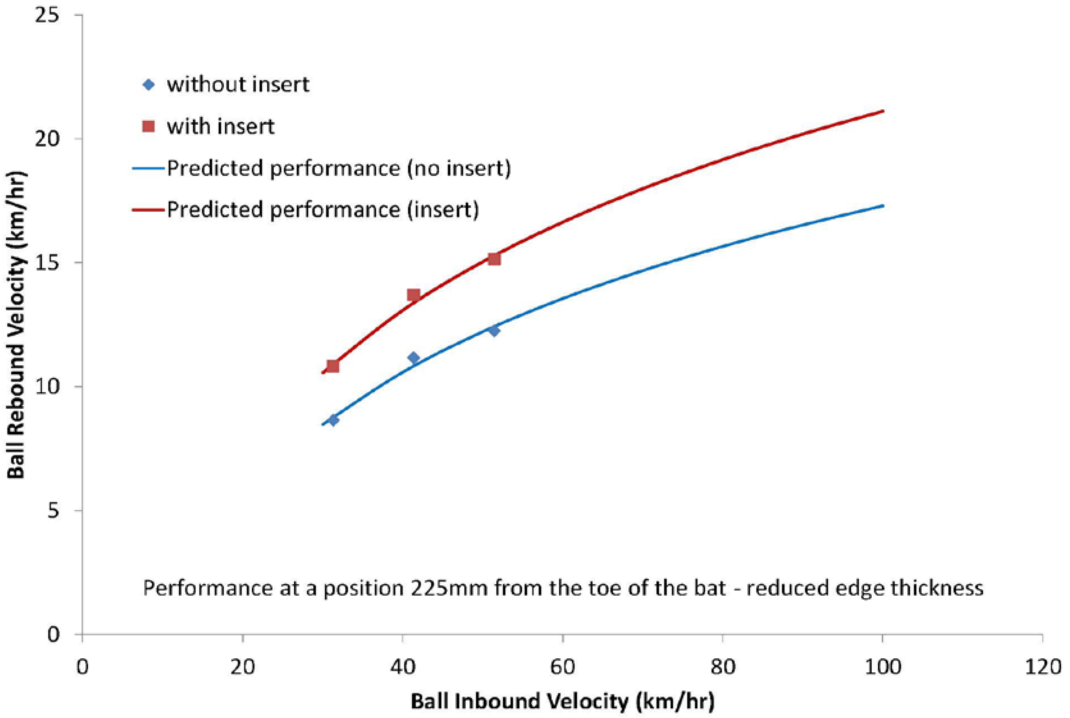

Figure 7. Improvement in predicted performance of cricket bat as a result of insert.

Ball Results

The rigid wall experiments results represent the dynamic response of a cricket ball as it impacts a rigid wall, as shown in Figure 8. The results from the FEA show that over the range of velocities that the tests were conducted the COR of the ball reduces slightly from 0.49 to 0.51 as the velocity is increased from at 31 km/hr and 51 km/hr respectively as seen in Figure 9.

The predicted performance uses a logarithmic fit to the data at three points which are about half of what would be expected in first-class cricket. The inserts act as a spring to absorb some of the energy from the ball's impact. The insert then releases energy as the force from the ball falls below the required force to compress the spring (insert) energy is imparted back on the ball so increasing the rebound velocity. The greater the force, the greater the stored energy in the bat, which can be released to the ball through the oak inserts. The thicker edges of the standard bat do not allow the insert to act as a spring at the range of velocities tested. As the velocity is increased, we expect there to be a noticeable improvement in the standard bat as velocity is increased to 100km/hr. Previous studies have shown that the COR of softball, baseball and cricket ball decreases linearly with impact speed (Bower, 2012; Smith & Duris, 2009; Stretch, Brink, & Hugo, 2005). The insert also seems to improve the torsional stiffness of the bat, reducing the overall twist in the blade.

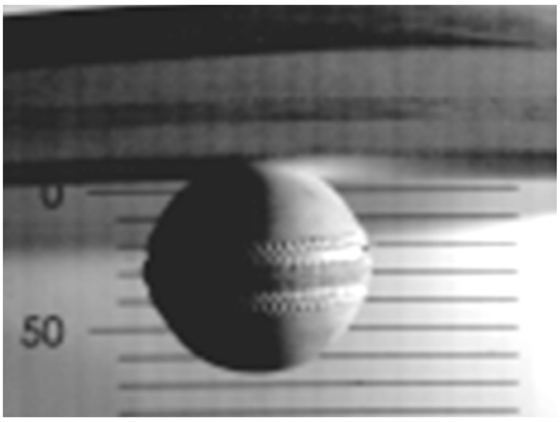

Figure 8. Image of ball impacting on the bat.

Conclusions

The aim of the current work was to investigate the difference in performance of a cricket bat with and without inserts as utilized by amateur batsmen facing amateur bowlers. The potential improvement of a cricket bat is two-fold; the rebound velocity of the ball can be increased while also reducing the weight by reducing the edge thickness or redistributing the mass to improve other sections of the bat.

The outcomes of this report show that the addition of a 6mm thick insert in the sides of a cricket bat can significantly improve a cricket bat's performance, both in the area of the sweet spot and the overall improvement in the COR of the bat.

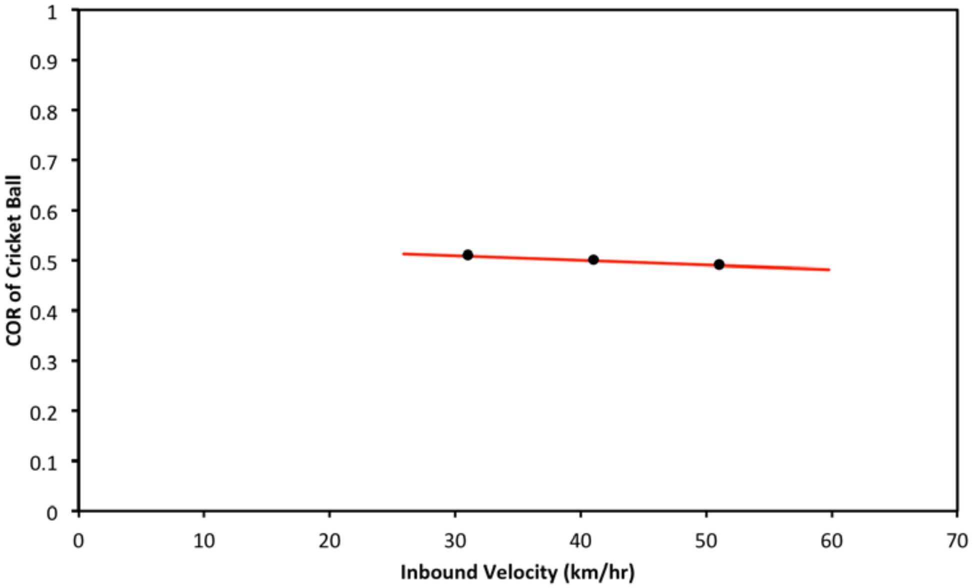

Figure 9. COR Results at the three experimental velocities.

The resulting increase performance from the bat modification may aid in the acquisition of skill and increase motivation in young and/or amateur cricketers, providing a better opportunity to improve their batting skill during their development stages.

The potential to utilise this type of insert could be in any design of bat to improve its performance without any additional modifications to the profile of the existing layout. The testing of the torsional stiffness could give further insight into the magnitude of the inserts influence on performance. Further testing at various inbound ball velocities is required to characterize the bat performance.

The work started on the FEA could be further refined as a useful tool to help designers test their design to predict the potential improvement from such a design without having to make prototypes. More research at high velocities typical of first class fast bowlers, over 100 km/hr could be of benefit to see if our prediction of performance is applicable.

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Research Profile

Two of the authors, Tony Kilpatrick and Luke Mulcahy, completed this work as part of their capstone project in final year of their Mechanical Engineering studies at Swinburne University of Technology under the supervision of Aaron Blicblau.