The Material Science of Cricket Balls and its Effect on the Game

Materials science has played an important role in many sports, with the evolution of materials causing a simultaneous improvement in sports equipment. However, some sports often regulate the materials and dimensions of the equipment it uses. Cricket is no exception, with some specifications to bat sizes and material, but very well defined specifications to the cricket ball used. However, even with the dimensions and materials mostly constrained, the minor (and sometimes incorrigible and unintended) differences in cricket balls can cause subtle changes in behavior that impact gameplay.

Cricket is a team sport played between bat and ball. The bowling team uses various bowlers to bowl the ball at the batsman (similar to a pitch in baseball), whose job it is to properly negotiate the ball by hitting it for runs, without getting out. The ball usually bounces once on the ground (known as the “pitch”) before reaching the batsman. This interaction with the pitch adds complexity to the behavior of the ball. The two main types of bowling are fast and spin. In fast bowling, the ball is thrown at speeds of around 110 to 160 kph in a straight initial trajectory towards the batsman. Fast bowlers also impart “swing” through the air on the ball (where the ball deviates away from the straight line), as the ball’s behavior is altered by the fluid dynamics of being hurled through the air (see later section for explanation). In the other option, spin bowling, the ball is imparted with revolutions by the bowler. Obviously, to achieve this, the bowling speeds are much slower, usually in the 70 to 100 kph range. Upon landing, the bowl grips the surface and turns in the direction spin was imparted. The amount of spin and bounce
achieved is very much a function of how dry and hard the pitch is. The hardness of the ball, the smoothness of the hemispheres, the prominence of the seam, and other factors, dictate the proclivity to achieve swing or spin by the bowler.

**Basic Anatomy of a Cricket Ball**

According to the Laws of Cricket, “the ball, when new, shall weigh not less than 5½ ounces/155.9 g, nor more than 5¾ ounces/163 g, and shall measure not less than 813/16 in/22.4 cm, nor more than 9 in/22.9 cm in circumference” [1]. A ball is used for 480 pitches (called “deliveries”) at a minimum before being replaced. This creates changes in its wear and properties as the game progresses, allowing different types of bowling to prosper at different times. At the international level, all three types of balls used comprise of a cork core (though in other leagues a mix of rubber and cork are used) that is about half the diameter of the complete ball (full specifications in British Standard BS 5993). The core is then covered in a quilt of five concentric layers of concentric cork sheet wound on by worsted yarn to reach close to the size of the full ball. Meanwhile, red tanned leather is cut into shape to four equal sizes that will eventually form the sphere covering the ball. Two pieces are each sown together without visible stitching, forming the two semi-spherical halves. These halves are each lined with two rows of machine stitching to keep them together. Then, the halves are placed over the yarn/cork ball and stitched to each other after compression to the right size. One row of additional stitching on each half over the overlapping region is done, so the final ball has a total of 6 rows of seam [2] [3] [4] [5]. The inside of a cricket ball is shown in
Figure 1 [6]. However, below the domestic level, the core can be different. Some common cores include the whole inside made of a composite cork and rubber mixture, less than 5 layers of cork/worsted yarn around the smaller core, composite cores, linear layers, two outer leather hemispheres stitched together (as opposed to four quarters) and other such designs [7].

Other than the three manufacturers mentioned above imparting variance due to the seam and stitching, as well as choice of leather and finishing, the color of cricket balls is also different across formats. For various reasons, white, red, and (recently) pink balls are used. The way the color is achieved, through dye and coatings, results in differences in the behavior of the ball as well.

**Physics of ball behavior – swing, spin & bounce**

With the amount of money involved in sports, vast studies have been conducted on the behaviors of the equipment used. Analogous to cricket, the aerodynamics of baseballs have been studied in depth and lots of literature has been written on the subject [8]. However, certain characteristic behaviors of the cricket ball specifically are discussed below. Swing bowling is when a ball is bowled at a batsman and there is significant deviation from the line of the ball. Three types of swing cause this behavior – conventional, reverse, and contrast. The types of swing are described below due to their complete characterization done by in previous studies [9].
In conventional swing, the seam is angled slightly away from the direction of the pitch. When the seam is angled, with more of the smooth side facing forward, a laminar boundary layer starts when the ball is facing forward, which wraps around the ball on the smooth side, but is tripped by the seam on the other side, thus becoming turbulent. The laminar boundary layer leaves the ball earlier than the turbulent layer on the other side, due to the principles of fluid dynamics. This is shown in Figure 2.

In reverse swing, the opposite occurs, and the ball deviates in the opposite direction to where the seam is pointing. In this case, the rough side is mostly shown to the front, and the incoming air separating into a turbulent flow boundary layer on both sides. On one side, however, the seam thickens and weakens the turbulent layer, causing it to separate earlier. This time the side force is in the opposite direction, and the ball behaves differently, as shown in Figure 2.

In contrast swing, the seam is pointed straight when the ball is released, and doesn’t play a role in the fluid dynamics. The smooth side naturally has a laminar boundary layer that separates earlier, compared to the turbulent boundary layer caused by the rough side, causing the ball to swing according to the side force towards the rough side. This is shown in Figure 2.
Computational Fluid Dynamics (CFD) studies of this behavior has confirmed theoretical results, and are shown in Figure 3 [10]. Based on the fluid dynamics of swing, the dependence on speed is often referred to. For conventional swing, it turns out that generally, the side force that creates spin on the ball, climbs gradually with speed of the ball, but drops drastically after a certain point. This point is dependent on seam angle, with a 30-degree seam seeing a drop-off after about 115 kph, and the 45-degree seam seeing a drop-off after 105 kph, as seen in Figure 4 [11].

There are two main ways of imparting spin on the ball – wrist and finger spin. In wrist spin, the force on the ball is imparted by the wrist, whereas in finger spin, the fingers are used to impart force, hence the names. The spin that occurs due to both is dependent on similar factors, such as the amount of friction the ground offers upon the ball landing, the amount of revolutions put on the ball, the direction the seam is pointing, and so on. Phenomena such as the Magnus Effect create huge variance in the types of behavior of the ball, including flight (increased upward velocity), dip (downward velocity), side-spin, and other such behavior. However, the common factor that ties it to the material of the ball is the subtle change in behavior based on the surface roughness of the ball, the hardness of the ball, and the prominence of the seam.

Across domestic (before the international level) and international cricket, a number of different types of cricket ball constructions are used, as long as they meet the weight and dimension specifications from BS 5993. These constructions primarily differ by their core, shown in Figure 5, and described in Table 1.
In England, five different types of cores are used. These are described in the table below:

Table 1 Cores of cricket balls used in England on which the study was conducted (Jarrat & Cooke, 2001)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Traditional</td>
<td>Cork small core with 5 layers of worsted yarn/cork sheet</td>
</tr>
<tr>
<td>Composite 1</td>
<td>Composite full core of rubber and coarse cork granules</td>
</tr>
<tr>
<td>Composite 2</td>
<td>Composite full core of rubber and fine cork granules</td>
</tr>
<tr>
<td>Rolled 1</td>
<td>Rubber small core wound with layers of rubber/composite (cork &amp; rubber) sheets</td>
</tr>
<tr>
<td>Rolled 2</td>
<td>Rubber center with alternate layers of rubber/composite (cork &amp; rubber) sheets</td>
</tr>
</tbody>
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The following describes a previously conducted study on the different cores [7]. Three samples of each type of core (as well as each whole ball) were tested thrice along the three principal axes (according to Figure 6). The mean peak load for each sample (and for each whole ball) along each axis is shown in Figure 7, along with the mean peak deceleration. The results of a compression test are shown for the cores and whole balls in Figure 8.

There is a clear inconsistency across axes when it comes to both rolled cores, as seen by their mean peak load, deceleration, and in the rolled whole balls. Similarly, there is an axially-dependent massive range of compression results in both rolled cores and rolled whole balls. Across all these parameters, the other cores and whole balls are fairly axially independent.
Separately, even though the cores and balls were consistent axially with themselves, they differed from each other quite significantly. This can cause differences in bounce and other forms of ball/pitch interactions. There is already a variance in the pitches produced in countries, as well as globally, with different types of soil used depending on the region, and different levels of moisture and hardness. With the players being required to adapt to these changes as part of the game, the consistent ball at the international level assures them any inconsistency is due to the pitch. However, if domestic players are facing variance in bounce and other properties due to the inconsistency of balls used, as well as the axis of landing of the ball (as is the case in the rolled cores), it makes the transition to international cricket harder, as the adaptability to surface is conflated with adapting to imperfect ball behavior.

Additionally, in the case of the rolled core balls, different bounce based on axis of landing can actually be dangerous for game play, as the batsman properly ascertain the height at which the ball will reach him based on where it lands.

Similar to the study above, an Australian study was conducted on five cricket balls with different cores [12]. The balls studied included two internationally used balls (Kookaburra, SG) and three domestic balls, as detailed in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Kookaburra (red)</td>
<td>Kr</td>
<td>Granulated cork and rubber core, machine-made, with cork layers wound with/without tension; 2 leather pieces</td>
</tr>
<tr>
<td>Gray-Nicolls (white)</td>
<td>Gw</td>
<td>Granulated cork and rubber core, handmade, with cork layers wound with tension; 4 leather pieces</td>
</tr>
<tr>
<td>Ball Type</td>
<td>Core Composition</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Regent (red)</td>
<td>Unknown core composition, handmade, with cork layers wound with tension; 4 leather pieces</td>
<td></td>
</tr>
<tr>
<td>Regent (white)</td>
<td>Granulated cork and rubber core, handmade, with cork layers wound without tension; 2 leather pieces</td>
<td></td>
</tr>
<tr>
<td>SG (red)</td>
<td>Cork or rubber core, handmade, with cork layers wound under tension; 4 leather pieces</td>
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Stiff-deflection tests showed that the Kookaburra ball is highly consistent in stiffness, and shows a dependence on the deflection rate. The Regent White balls were highly inconsistent, but developed two groups (hard and soft) that had completely different stiffness-deflection curves. The Gray-Nicolls balls had a wide range of values in the curves as well, but followed a pattern, unlike the Regent White which had drastically different patterns. The Regent Red also had different patterns, but the values were in a closer range. The SG balls were grouped by core (cork or rubber), with differences in curves between the two cores, but quite consistent within each type. Similarly, the balls were tested for their peak force, displacement, and time to peak force,
versus initial velocity. These values govern the contact point interaction a batsman feels when he hits the ball with the bat. A softer new ball will have a lower impact force, have a larger deflection (and thus greater area of contact), and a longer contact time, making it easier for batsman to be precise, and allowing room for error. Figure 10 shows the results for the balls tested, along individual planes, and overall. The Kookaburra is clearly the softest ball and most forgiving for batsman from a hardness perspective. Importantly, the Gray-Nicolls and Regent White balls behave inconsistently with regards to stiffness, which is a quality control problem, and can cause problems with game play and are potentially unsafe.

The three internationally used cricket balls (Kookaburra, Duke, SG) vary mostly by the seam stitching. The biggest impact is from the prominence of the seam, and the longevity of the seam lasting. The Kookaburra is machine stitched, whereas the Duke and SG are carefully hand-stitched, allowing for tighter stitching.

For applying wrist spin, the seam is unimportant, as the ball is held in the palm of the hand, while the revolutions are imparted with the wrist. For finger spin, however, the grip a bowler is able to achieve on the seam is directly related to how easy it is to impart spin. Thus, the SG and Duke balls, with their prominent seam that lasts longer, is better suited to finger-spin rather than wrist spin. Regarding swing bowling, the seam helps trip the boundary layer into turbulence as explained above. However, this is not the case for contrast swing, and this type of bowling can continue even when the seam disappears. However, the prominence of the seam in the Duke and SG creates a higher turbulent layer initially, which can have different effects. All else being the same, this higher seam will create a thicker turbulent layer that will leave earlier. This should decrease the effect of conventional swing, and increase the effect of reverse spin. However, the
leather and outer coatings of the ball have as much as a role to play (if not more) on the proclivity to swing.

**Leather**

The leather used in making cricket balls is raw heavy cowhide (SG, Duke) or raw steer-hide (Kookaburra) [5] [13]. International quality balls are alum tanned (for all three manufacturers), but other cricket balls can be vegetable tanned, zirconium tanned, and zirconium-chrome combination tanned [14]. The raw hides are cured to prevent bacterial breakdowns, before the hair and flesh are removed, and then pickled in preparation for tanning. The process of tanning causes a chemical reaction to take place between the protein in the skin and the tanning agent. This prevents downstream bacterial formation [15]. Alum (Al$_2$SO$_4$ + K$_2$SO$_4$ + 24H$_2$O) is prepared by mixing solutions of aluminium sulphate with alkaline sulphates, and evaporating the fluid. In a complete saturation during alum tanning, the skin absorbs 7 to 8 per cent of alum that splits, with the aluminum sulphate precipitating on the fibers, while the potassium sulphate remains in solution [16]. The alum tanned skin is whitish and is conducive to producing red, white, or pink balls later on.

The tanned leather must have certain physical and chemical properties. The leather must have a minimum tensile strength of 25 MPa (except for alum-tanned: 20 MPa), and a maximum elongation at break of 35% (except for alum-tanned: 50%). The maximum water absorption percent by mass should be 40% in 30 minutes, and 45% in 2 hours as well as 24 hours. [14].

For red dyed cricket balls, the leather is aniline-finished. Synthetic buck fat (warm liquid wax) is added onto the surface, darkening the leather (makes pale red leather dark red) and changing its
properties. It makes the leather somewhat water repellant (following the specifications mentioned above), and more importantly, provides a waxy surface under the final coating, that gives the user the ability to polish the ball using heat from friction (rubbing). This “polishing” by the bowlers is done on one side of the bowl, to enable swing bowling. The friction causes the leather to release the previously absorbed greases, and maintain a shine on one side. The aniline finishing is not colorfast, and thus, the players clothing, as well as bats used to hit the ball, get red over time. After the waxing, the ball is then shellac coated with heat application [15].

For white balls, a polyurethane paint-like fluid and heat treated to bond with the leather, after which another coat of clear polyurethane-based topcoat is applied for protection. These coatings make the white ball behave like plastic when it comes to polishing, and doesn’t allow for the waxy polishing to occur. On the flip side, however, the extra coating completely covers up the imperfections caused by the hidden seam (see figure 6) and allow for a smoother initial ball, and thus more potential swing movement [17]. The bright-pink color required for day-night Test matches is achievable by dyeing. However, when the post-dyeing buck fat application is conducted, the color darkens, thus causing it to lose its brightness and visibility under lights. Therefore, the color in pink ball leather is also achieved by coating mechanisms [15].
References


