EVALUATING TEST METHODS USED TO CHARACTERIZE SOFTBALLS

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ABSTRACT: The performance of baseball and softball bats can depend strongly on the properties of the ball. Standard test methods exist to measure the ball weight, hardness and coefficient of restitution (COR). Ball hardness is measured in a quasi-static compression test and the COR is measured by impacting the ball against a rigid plate. Little has been done to determine how these properties relate to the measurement of high speed bat-ball impacts. This study considers the rate dependence of ball compression, COR, degradation from multiple impacts, and humidity. A dynamic compression test, where the ball impacts a rigidly mounted load cell, was used to compare static and dynamic compression. The balls were tested as a function of speed to determine the appropriateness of extrapolating low speed test results to high speed play conditions. The compression and COR of balls conditioned to dry and humid environments were compared to determine if humidity can be used to control ball hardness in laboratory tests. A strong correlation between the static and dynamic ball hardness was observed, although the correlation involved an offset. The frequency of ball testing (which is not controlled in any standard) was observed to affect the ball's measured response. The change in the ball's response was temporary and found to be related to its temperature and viscoelasticity. The response of balls impacted 100 times was nearly unchanged when allowed to recover between tests. Humidity was observed to have a negligible effect on a ball's COR and dynamic hardness, but a measurable effect on its static hardness.

INTRODUCTION

Advances in the design and manufacture of baseball and softball bats have improved their hitting performance significantly. Regulating agencies have placed limits on the hitting performance of bats in an effort to maintain a balance between the offensive and defensive aspects of the game. Bat performance may be measured and quantified in a number of different ways. All methods of determining bat performance are subject to experimental error and manufacturing deviations. Since performance is given as a limit, small changes in performance can have a large competitive and regulative effect. There is interest from the part of regulating agencies and manufacturers, therefore, to improve the accuracy and repeatability of determining bat performance. The current study considers the effects of softballs in measuring bat performance.

BACKGROUND

The two properties that are most commonly used to describe a softball are its coefficient of restitution (COR) and static compression (ASTM F1887, 2002; ASTM F1888, 2002). The COR is used to measure the energy of the ball that is lost during impact with a rigid wall (Cross, 1998), while compression is a measure of the ball's hardness. Both the ball COR and compression can affect a bat's hitting performance. The effect of compression on bat performance is primarily due to barrel deformation. Performance generally increases with barrel deformation. This so called trampoline effect is enhanced with increasing ball compression (Chauvin, et al., 1997).

The vast majority of softballs are made from a polyurethane core with either a synthetic or leather cover. The synthetic core allows a wide range of ball COR and compression values to be achieved. Balls are typically denoted as xx/yy, where xx indicates ball COR and yy is the force in pounds needed to compress the ball by ¼ inch and is a measure of ball hardness. The ball COR and compression are often used as another means of controlling bat performance and game play.

There is some concern whether the current practices of measuring ball properties adequately describe its response. The ball COR, for instance, is measured against a rigid and flat surface at speeds that are lower than are used in play. Ball compression is measured at a displacement rate that is 10,000 times slower than occurs in play. While the use of these methods represented a prudent starting point when they were introduced, little has been done to justify their continued use. There is also a paucity of information concerning how the properties of the ball change over time, with repeated use, humidity or temperature. Much of the information that does exist is related to baseball, which uses a multi layered ball of varying materials that can behave much differently than a polyurethane softball (Chauvin, et al., 1997).

In the following we will compare the response of softballs from two different manufacturers, as a function of COR, compression, and speed. We will also consider the effects of the number of impacts, temperature, and humidity/conditioning on its response.

DYNAMIC COMPRESSION

The effect of ball hardness can be viewed from the perspective of impact force. This has been achieved by firing balls toward a rigidly mounted load cell, as shown in Fig. 1 (Axtell, 2001; Chauvin, et al., 1998; Giacobbe and Scarton, 1997; Hendee, et al., 1998). The focus of past work has been toward human safety and developing numerical models. A result of this work was the observed linear correlation between the dynamic and static compression (Hendee, et al., 1998). This observation will be explored further in the current study.

As shown in Fig. 2, force can be measured as a function of time from a ball impacting a load cell. The area under the curve is the impulse imparted to the ball

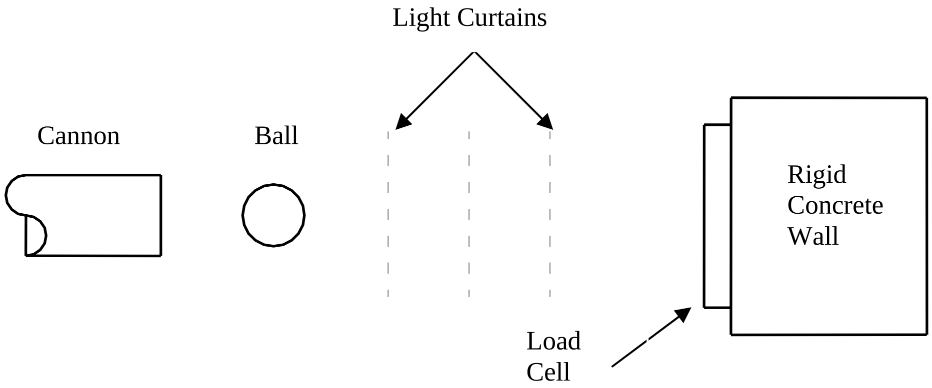

Fig. 1 Experimental test setup for dynamic compression.

from the collision. The peak force during contact is denoted as the dynamic compression. The peak force is relevant to bat performance, since it governs the deformation that would occur in a bat.

Dynamic compression is shown as a function of static compression for three ball types from two ball manufacturers in Fig. 3. A linear correlation between the two measures of ball hardness is consistent with previous observations of baseballs (Hendee, et al., 1998). The dynamic compression presented in Fig. 3 has been normalized to the initial ball momentum to remove the effects of variation in pitch speed or ball mass. The normalization also allows direct comparison of results measured at different pitch speeds. Tests conducted at 90 mph, for instance, agree closely with that shown for 60 mph.

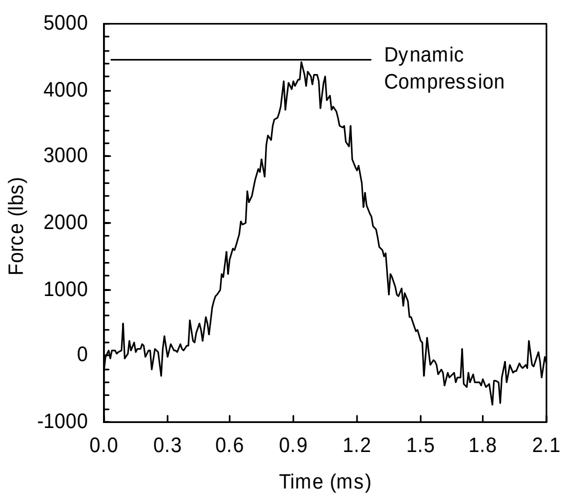

Fig. 2 Impact force of a 0.44/375 ball from manufacturer A at 90 mph

It should be noted that an extrapolation of the data in Fig. 3 produces a non-zero y-axis intercept. This may be expected since a ball of negligible hardness will still produce an impact force when delivered at a high speed. This implies that static and dynamic compression should not be taken as directly proportional (an offset is needed).

It is possible to perform ball COR

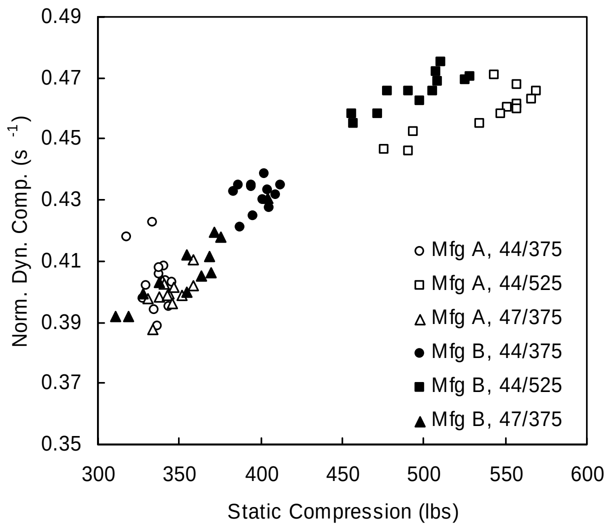

Fig. 3 Normalized dynamic compression at 60 mph vs. static compression. The dynamic compression is an average of ten impacts.

measurements while measuring dynamic compression. There is concern, however, that the compliance of the load cell could affect the COR measurements. The load cell used in the current work had a stiffness of 50Mlb/in. The average COR of 12 balls impacted with the load cell decreased 0.7% in comparison to their rigid wall COR value (which is within the repeatability of the COR measurement). Therefore, the effect of the load cell on ball COR measurements for the current work was considered negligible. The ball momentum change from the rigid wall collision can be found from the impulse of the load cell by integrating the force over time. The average momentum from the load cell and the light gates were within 1% (using 12 balls impacted at 60, 90, and 110 mph). The electrical noise and vibration of the load cell increased the variation by a factor of 10 over the light gates, however. Work is ongoing to improve the reliability of the impact force measurement.

Ball COR was measured on 12 44/375 balls at 60, 90, and 110 mph. Ball COR was observed to decrease linearly with increasing pitch speed (16.5% between the 60 mph and 110 mph impacts). Ball COR measurements at 60 mph likely underestimate the energy lost at higher speed ball-bat impacts.

Some believe that the ball COR should be measured against a rigidly mounted cylindrical surface to better simulate bat testing and game conditions. The effect of a rigid cylindrical surface was considered by attaching a solid half cylinder of 2 ¾” diameter (analogous to a softball bat barrel) to the load cell. Ball COR and dynamic compression were observed to decrease by 6.5% and 7.8%, respectively, for 90 mph impacts. The cylindrical impact surface effectively reduces the contact area of the ball at impact. The reduced area results in greater local deformation inside the ball, which contributes to the energy loss or reduced COR. The reduction in dynamic compression is also associated with increased local ball deformation, as evidenced by the 7.5% increase in contact duration between the flat and cylindrical contact surfaces.

The limited number of balls used in this comparison (24) is not sufficient to determine conclusively the necessity of using a cylindrical surface. The results show, however, that low speed, flat surface ball tests produce ball COR measurements that are higher than would occur in a bat-ball impact. Ball COR tests using a cylindrical surface were shown to be feasible and added minimal effort to the test. It should be noted, however, that standard ball pitching machines would not likely have the accuracy needed for cylindrical surface COR measurements.

DEGRADATION

Most test standards and protocols limit the number of impacts that a ball can undergo before being deemed unsuitable to measure bat performance (ASTM F2219, 2002; NCAA, 1999). These limits remain in place despite results that show baseball COR and compression are constant through 100 impacts (Axtell, 2001). Synthetic balls can have greater temperature and viscoelastic effects than the natural materials they replaced. Little information exists concerning the durability of synthetic softballs.

The dynamic compression and COR of three softballs impacted 100 times at 90 mph consecutively (within 120 minutes) are presented in Fig. 4. The data appear to suggest a significant change in response as the ball was impacted. The change may be related to test-induced ball heating, which increased the ball temperature by 10° F over the 100 impacts. To separate the effects of temperature and ball impacts, another group of balls was tested intermittently. The procedure involved 10 consecutive impacts, followed by a minimum 60 min. pause for the ball to return to lab temperature. (The ball temperature increased approximately 5° F during the 10 impacts over 10 minutes.) As shown in Fig. 5, the dynamic compression and COR appear independent of impact number. This suggests that ball temperature and testing frequency may play a more important roll in measuring bat performance than limiting the number of ball impacts. Similar results were obtained from a group of balls impacted repeatedly against a cylindrical surface.

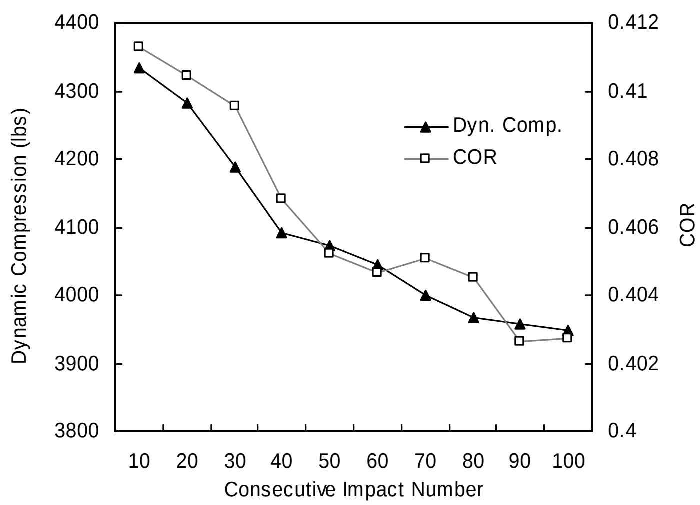

Fig. 4 Dynamic compression and COR as a function of consecutive impact number (90 mph, two 0.44/375 balls). Each data point is the average of ten impacts per ball.

ASTM 1887 requires the ball to be rotated 90° between each test, and allows only the four main ball surfaces to be impacted to minimize string contact. As observed in Fig. 6, a pattern is apparent

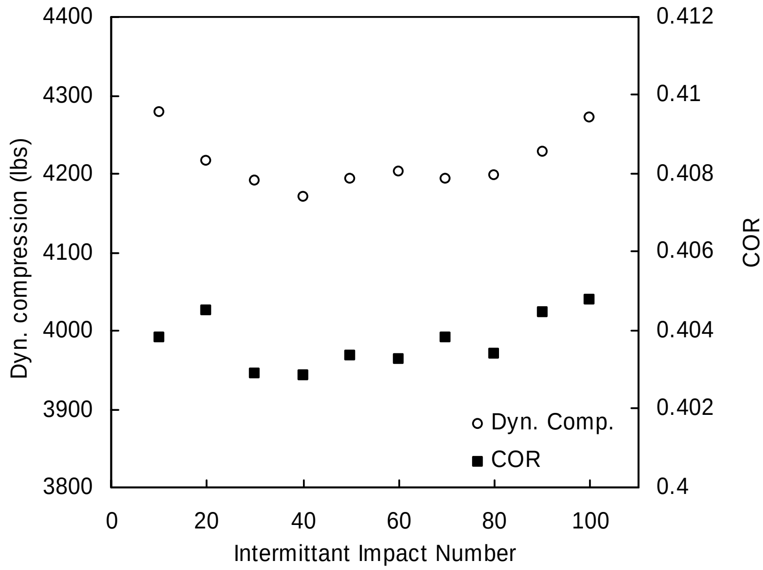

Fig. 5 Dynamic compression and ball COR as a function of intermittent impact number (90 mph, two 44/375 balls). Each point is the average of ten impacts from each ball, where balls were allowed to recover every 10 impacts.

when the first 4 impacts are compared to the subsequent impacts. Since the COR increases after the first four impacts, the effect is probably not related to temperature. It is possible that the increase in COR after the fourth impact is related to the viscoelastic response of the synthetic ball. It is advisable, therefore, that both internal heating and viscoelastic effects should be considered when evaluating allowable ball test frequencies.

As shown in Fig. 4, the ball COR was observed to decrease by 0.001 over the first 10 impacts. It is recommended, therefore, that a ball should not be impacted more than 10 times in one hour, or more than one impact per minute. Balls that are to be reused in subsequent bat tests should be given a minimum of one hour in standard laboratory conditions to recover following a sequence of impacts before they are to be used again.

Conditioning requirements are often placed on balls before they may be tested. The effect of ball conditioning was examined by monitoring the weight gain of five balls taken from a 30% RH environment to 50% RH. It was observed that the balls require approximately 14 days to reach equilibrium. The effect of humidity was further examined by comparing the COR and dynamic compression of a dozen balls conditioned at 30%RH and 55%RH for a minimum of 14 days. Going from the dry to humid environments, ball COR and dynamic compression were observed to increase by less than 1%. Static compression, however, decreased by 21% over the same change in humidity. This suggests that the rate effects of softballs may depend on their moisture content.

SUMMARY

This study has considered a number of methods of measuring the properties of softballs. Static measurements of ball hardness were observed to strongly correlate with dynamic measurements. An offset associated with the ball's momentum was observed in the correlation, however. Simultaneous ball COR and dynamic compression measurements appear feasible and were shown to have a negligible effect on the COR measurements. Test induced internal heating of the ball was observed to affect its dynamic compression and COR value. A ball test frequency of 10 impacts per hour is recommended to reduce this effect in determining bat performance. A recoverable viscoelastic effect was apparent when the first impact of a ball's surface was compared to subsequent impacts of that surface. Test standards should consider this fact for balls impacted multiple times. Static compression was observed to decrease with increasing humidity. Humidity did not appear to have a measurable effect on dynamic compression and COR.

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