Proceedings

A Study of the Interaction between Batting Cage Baseballs and Pitching Machine †

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† Presented at the 12th Conference of the International Sports Engineering Association, Brisbane, Queensland, Australia, 26–29 March 2018.

Published: 25 February 2018

Abstract: Batting cage pitching machines are widely used across the sports of baseball and softball for training and recreation purposes. The balls are specifically designed for the machines and for the environment to ensure high durability and typically do not have seams. Polymeric foam balls are widely used in these automated pitching machines for batting practice in a cage environment and are similar in weight and size compared with the regulation balls used in leagues. The primary objective of this paper is to characterize the polymeric balls and their interaction with the pitching machine. The paper will present measured ball properties and measured relationships between various pitching machine parameters such as wheel speed, and the ratio of wheel speeds on the ball exit velocity and rotation. This paper will also characterize some of the effects of wear on the baseballs and wheels from their prolonged use.

Keywords: pitching machine; baseball; wear; foam; batting cage

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1. Introduction

Batting cage pitching machines are widely used in the sport of baseball and softball for training and recreation purposes. In consumer batting cage settings, these machines typically dispense elastomeric foam (e.g., polyurethane [1]) baseballs specifically made for batting cage practice. These batting cage baseballs cost less than real baseballs, are significantly more durable, and typically have no seams or seams with a lower profile, as compared to regulation league baseballs, in order to minimize interference with the pitching machine wheels and to reduce wheel wear.

To date, however, minimal study has been performed to understand the pitching consistency of these batting cage balls for typical use and the effect of ball wear on their performance. This research first characterized the physical properties of two types of elastomeric foam batting cage balls (yellow and orange) with regards to their hardness, density, the variation of physical properties within a ball, and the variation between different ball types. The pitching behavior of these balls was investigated by capturing and analyzing high-speed video of the balls as they entered and exited the pitching machine wheels, as well as their flight path and their horizontal and vertical impact location for a pitch distance of 15.3 m. The consistency of the ball impact locations for a single pitching speed, and the variation in pitch consistency between different pitching speeds, was measured. The evolution of the ball physical properties and their effect on pitch consistency between new balls and end-of-life balls that are at the end of their pitching life (i.e., >100,000 pitch cycles) were also investigated.

This work serves as an initial guide for the design of the interaction of pitching machine baseballs and the pitching machine for consistency in targeting speed and location. The primary objective of this paper is to characterize the polymeric balls and their interaction with the pitching machine. The paper will present measured properties including coefficient of restitution, dynamic stiffness, compression, hardness, and density of several variations of the baseballs. The paper will also present the measured relationship between various pitching machine parameters such as wheel speed, and the ratio of wheel speeds on the ball exit velocity and rotation. Additionally, this paper will characterize some of the effects of wear on the baseballs.

2. Materials and Methods

2.1. Materials

The batting cage baseballs studied in this work are elastomeric foam balls made of polyurethane. Two ball types—orange and yellow were used in this study. Orange and yellow balls that were used long-term in the field are referred to as end-of-life (EOL) in this study. The EOL balls have unknown history but life is estimated to be likely >100,000 pitch cycles, which has been shown to reduce foam stiffness by >20% [2]. In addition to the virgin orange and yellow balls, EOL orange and EOL yellow balls were also studied for their properties. Orange, EOL orange, yellow, EOL yellow balls are shown in Figure 1.

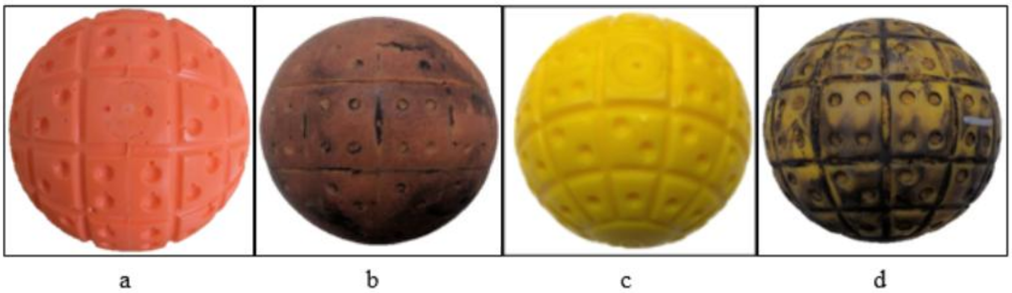

Figure 1. Ball Types: (**a**) Orange Ball; (**b**) EOL Orange Ball; (**c**) Yellow Ball; (**d**) EOL Yellow Ball.

2.2. Experimental Methods

All batting cage balls were stored for a minimum of two weeks in the University of Massachusetts Lowell Baseball Research Center, a laboratory with an environmentally controlled temperature of 22 ± 2 °C and 50 ± 5% relative humidity, prior to any testing.

2.2.1. Physical and Impact Characterization

The mass, circumference, hardness, density and compression of balls were measured. The ball hardness were measured using Shore-A with tip diameter of 1.4 mm for both the inside as well as outside (skin). The hardness distribution within the interior regions of the ball was measured at radii of 6, 12, 18, 24, 30 and 36 mm. The material densities were measured by immersion. Ball compression testing was performed for three different positions [3].

The impact properties of the balls were characterized using coefficient of restitution (COR) and dynamic stiffness (DS) testing. DS tests were performed with an 85-mph impact velocity and the test records the force exerted during the impact [4]. The COR is a measure of the dynamic performance of a baseball. The COR is a numerical value determined by exit speed of the ball after contact with a flat surface divided by the incoming ball speed before contact with the surface [5].

2.2.2. Pitching Machine Experimental Setup

The effects of the ball-pitching machine interaction were studied using the pitching machine pictured in Figure 2 To relate the wheel speeds to the set dial speed, the wheel rotational speed corresponding to each dial setting was tracked using a hand-held tachometer and by tracking a point marked on the wheels using high speed video camera recording at 1000–2000 frames per second.

These high-speed images were analyzed in the open-source image analysis software package (ImageJ) to calculate the wheel rotational speed.

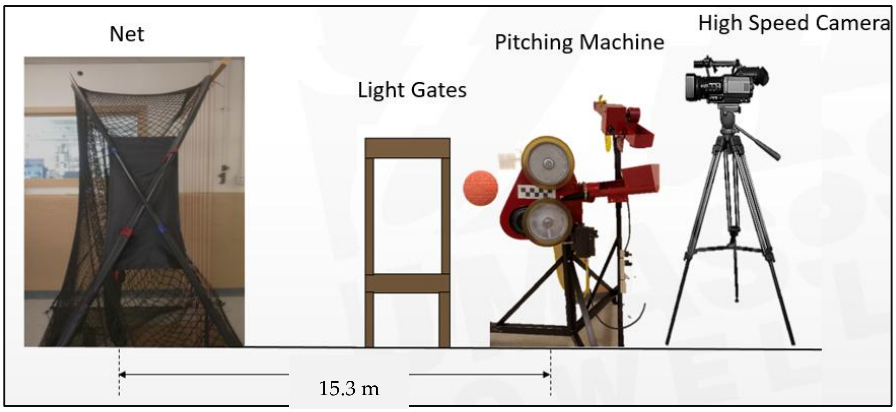

Figure 2. Schematic of the test set-up for long-range study to investigate ball inconsistency.

2.2.3. Effect of Orientation and Ball Exit Speed

The high-speed camera was set up facing the pitching machine wheels to observe the ball exit speed as a function of ball orientation. The images of the ball as it enters and exits the machine were captured at 2000 to 3000 frames per second. In order to observe the effect of orientation on the ball speed, balls with six different orientations (i.e., gate, opposite end of gate (GateOE), north and south between the wheels, gate facing the camera referred as GateFront, and opposite of the gate facing the camera referred as GateBack) were shot from the pitching machine at a speed of 1800 rpm for the lower wheel. The speed was calculated using image analysis of the high speed recordings.

2.2.4. Pitching of Baseballs from Long Distance

The consistency in the pitch trajectories and location at the home plate position was studied with imaging and analysis of long distance pitches. The pitching machine was set at a distance of 15.3 m from the net as shown in Figure 3. The camera was set up behind the pitching machine and light gates with a chronograph were setup at a distance of 0.3 m from the center of the pitching machine wheels to record the exit speed of the ball. Directly on the front of the net were positioned 17 strings hung spaced at a lateral distance of 38 mm from each other. The strings that were hit by the ball were displaced and the affected strings noted. The ball rotation and the location of the ball as it hits the target were determined from the images of ten balls of each type captured using a high-speed camera and were recorded at a frame rate of 500 frames per second. The machine was aligned with the target when orange and yellow balls were pitched only for ball exit speeds of 22 m/s. For ball exit speed of 18 and 34 m/s, the same machine alignment in the *X* direction as for 22 m/s was used; however, the machine was aligned with the target in *Y* direction. Image analysis was used to analyze both the impact location and the rotational speed of the ball by tracking a black dot marked on each ball.

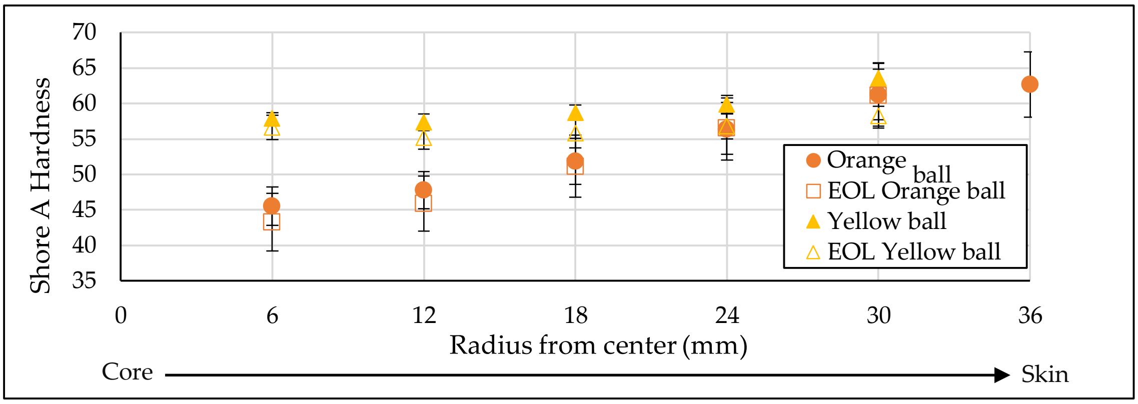

Figure 3. Inside hardness with error bars represent one standard deviation at each position.

3. Results

The initial circumferences of the cage baseballs were measured to be 8.92 in., while the EOL yellow baseballs reduced in circumference to 8.82 in and EOL orange baseballs reduced to 8.59 in. The average mass of the yellow balls was 5.14 oz, while the less dense orange baseballs were 4.80 oz. Both sets of EOL baseballs reduced in weight as the skin layer was worn off. The densities of the material across the radii of the baseballs also varied. The Yellow baseballs ranged from 0.65 g/cm^3 in the center to 0.87 g/cm^3 near the surface. The orange baseballs ranged from 0.55 g/cm^3 in the center to 0.81 g/cm^3 near the surface. Linked with the material density, the hardness of the interior of the balls was softer at the core of the ball than at the surface. Figure 3 shows the hardness values for the different ball types. The COR values of the batting cage baseballs averaged 0.486 while a standard collegiate baseball averaged 0.545 for COR. The EOL baseballs did not differ in performance from the original cage baseballs. Figure 4 shows a force-time plot of the high speed DS impacts for four baseballs.

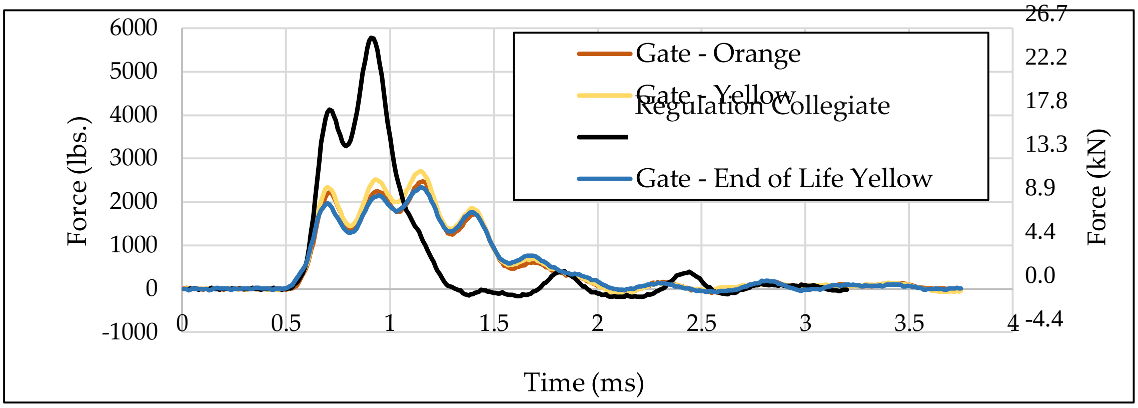

Figure 4. Impact characterization: Force/Time curve for impacts.

The pitching machine baseballs are propelled to speed by two wheels spinning in opposite directions. Figure 5 shows high speed images of the ball entering from the right side and exiting the wheels on the left side. The images capture the rotation of the ball as the lower wheel is rotating faster than the top wheel. The four images are presented in time intervals of 2.25 ms.

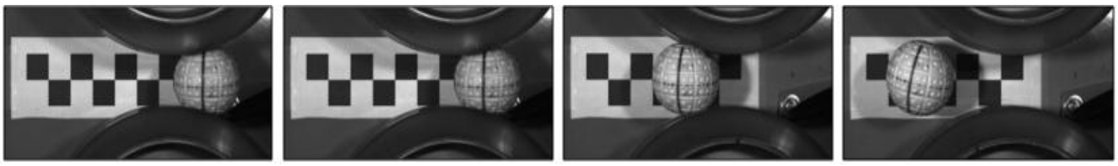

Figure 5. High-Speed images of ball as it enters and exits the pitching machine.

Long distance pitching of the baseballs was used to measure the consistency of the pitching for the various ball types and for various speeds. The pitch speed, spin rate and location of each pitch were all measured and average and standard deviation values for speed and rotation are recorded in Table 1. The locations of each pitch were recorded based on video analysis with visual assistance from the strings hung at the net. Those location values are presented in Figure 6 for the yellow balls. Due to space requirements, only the pitch locations of the yellow baseballs, but the orange balls were similar.

Figure 6 shows the locations of each pitch for the yellow baseballs (both original and EOL). The width of a strike zone for a batter is 0.43 m (17 in.) and the scales for the three plots are ±0.51 m (20 in) in both directions. The solid shapes are the original baseballs, while the hollow shapes are the EOL baseballs.

Table 1. Results of long-distance pitching experiments.

Ball Type	Wheel: 1600 ± 2 rpm		Wheel: 1800 ± 2 rpm		Wheel: 2400 ± 2 rpm	
	Speed (m/s)	RPM	Speed (m/s)	RPM	Speed (m/s)	RPM
Yellow	18.3 ± 0.4	754 ± 80	21.9 ± 0.3	701 ± 52	33.1 ± 0.3	1633 ± 46
EOL Yellow	18.4 ± 0.1	667 ± 48	22.8 ± 0.4	665 ± 56	33.1 ± 0.4	1727 ± 80
Orange	18.3 ± 0.2	794 ± 28	21.9 ± 0.4	767 ± 45	33.1 ± 0.1	1573 ± 48
EOL Orange	18.8 ± 0.1	775 ± 23	22.3 ± 0.9	745 ± 45	33.2 ± 0.1	1727 ± 70

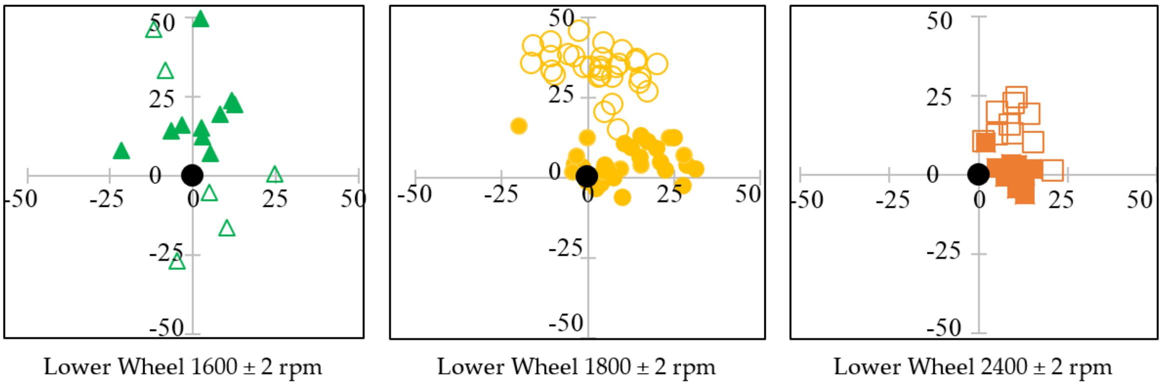

Figure 6. Results of long range studies of yellow baseballs (original-solid markers/EOL-hollow markers) axes units are cm.

4. Discussion

The aim of this study was to characterize the parameters that affect the consistency of flight of batting cage baseballs. The parameters considered include: physical properties of elastomeric foam balls with regards to their mass, circumference, hardness, density, ball compression, coefficient of restitution, impact behavior, variation of these properties within a ball and between different ball types, the pitching consistency of these balls for a typical user, and the effect of wear on the ball performance.

The mass of the batting cage baseballs were similar to regulation baseballs. The mass of polymeric foam balls, i.e., orange and yellow balls moderately decreases (10% and 6%, respectively) towards their end-of life (EOL) as material is worn from the ball surface. Due to the unknown number of cycles to which each ball type was subjected, the wear rates and the relative wear rates of yellow and orange balls is unknown. The circumferences of the balls of polymeric foam balls were also similar to regulation baseballs. Towards their end of life the circumferences decreased by 3.25% and 1.25% for yellow and orange balls, respectively. The variation in mass and circumference of balls within a lot and from lot-to-lot was minor. The density and interior hardness of foams balls decrease from the surface of the ball to the ball's core. Yellow balls possessed both higher density and greater hardness values in comparison to orange balls. The hardness values for newly manufactured balls and for EOL balls were very similar. Overall, the consistency between the baseballs, would likely not contribute to any substantial flight differences, except for potentially extreme wear to the surface of the ball from prolonged use.

The elastomeric foam ball types were substantially lower compression compared with standard collegiate baseballs. Impact characterization studies on the polymeric foam balls indicated that the polymeric foam balls were softer not only under quasi-static compression test but also under dynamic conditions. These compression tests and DS tests were partially performed to investigate the potential for the batting cage baseballs to contribute to the denting of bats. Both the quasi-static and dynamic tests indicate that the batting cage baseballs are substantially softer than regulations collegiate baseballs. Hence, the baseballs should have less ability to dent bats compared with standard regulation bats.

The ball interaction with a pitching machine was characterized for velocities ranging from 17 to 34 m/s. The higher rotational speed of the bottom wheel relative to the top wheel generates backspin and the orientation of the ball on entry into the pitching machine wheels did not have a measurable effect on the ball exit speed. The ball pitching study at 15.3 m distance identified that both the ball types were more consistent in their home plate location and higher in backspin at exit speed of 34 m/s than exit speeds of 18 and 22 m/s. The original balls appeared to be more consistent than EOL balls.

5. Conclusions

In conclusion, variation in physical properties between balls within a lot and from lot-to-lot was minor. Balls that were towards their end-of-life were less stiff, less massive and softer than newly manufactured balls due to wear of the skin (surface) from repeated use in pitching machines. The wear of the ball was restricted to the ball skin and skin layer of the ball had an effect on the physical properties of the ball. Pitching consistency decreased with ball wear. The balls pitched at higher exit speed (i.e., 34 m/s) were more consistent in hitting the target than at lower exit speeds (i.e., 18 and 22 m/s).

Acknowledgments: This material is based upon the work supported by J&J Amusements, Inc. Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the views of the J&J Amusements, Inc.

Conflicts of Interest: The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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