A performance and injury risk assessment study analyzing composite-based and wood-based softball bats

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INTRODUCTION

Over the past five years, there have been numerous injuries and even fatalities in the sport of softball involving the use of high-tech, composite-based softball bats (Table 1). We theorize that the introduction of composite-based material bats combined with the use of polyurethane softballs is the leading cause of recent softball injures and fatalities. To test and validate this theory, we have set up a controlled indoor and outdoor study comparing the performance of composite-based softball bats against a wooden softball bat that is used as a performance baseline.

It has been shown that there has recently been a significant increase in the performance of softball bats (McDowell, 2004, McDowell and Ciocco, 2005, McDowell and Ciocco, 2006). This increase in performance is directly related to the recent introduction of composite-based material softball bats that are currently used extensively at all levels of play. In the United States, 19.8 million athletes play slow-pitch softball (Ramsey and Smith, 2003) as a recreational activity. A recent literature review investigated interventions to prevent softball related injuries (Pollack, et al., 2005). This paper concluded that few studies exist on the intervention to reduce injuries during a softball game. They recommended that basic studies describing the nature, severity and risk factors for softball injuries in a variety of populations are needed, followed by additional intervention evaluation studies aimed at modifiable risk factors. They also concluded that in order to make the sport of softball safer for all levels of play, realistic safety information is needed.

A recent review article (Nicholls, et al., 2004) investigated the current literature relating to impact injuries and the role of equipment performance in the sport of baseball and surmised that batted-ball speeds from non-wood bats can reach velocities potentially lethal to defensive players. An impact study (Heald and Pass, 1994) indicated that skull fracture has been shown to occur at impact speeds of 25.9 m/s (58 mph) in cadaver heads using baseballs. A theoretical study using the Gadd Severity Index and Head Injury Criterion (Crisco, et al., 1997) predicted likely head injuries due to impact with a standard baseball at an impact speed as low as 16.5 m/s (37.0 mph). It must be noted that these studies employed baseballs, which are often much softer, and approximately 30% lighter than a typical softball (McDowell and Noebe, 2000).

Another study (Nicholls, et al., 2003) compared ball exit velocity between metal and wood baseball bats and indicated that a metal bat swung by an experienced hitter can produce ball exit velocities exceeding that demonstrated by a robotic hitting machine, which is what is currently used in the sport to determine bat safety. A batting cage study comparing performance differences between metal and wood baseball bats was conducted using high-speed cameras measuring 3D positions of baseballs (Greenwald, et al., 2001). This study showed that metal bats improve batted-ball speed performance over wood bats and that all players tested were able to generate batted-ball speeds exceeding 44.7 m/s (100 mph). A similar study (Crisco, et al., 2002) indicated that there was an increase, on average, in the performance of aluminum bats when compared to wood bats.

The sport of baseball and slow-pitch softball have significantly different safety concerns. The sport of slow-pitch softball is inherently more dangerous due to the fact that the players are 10-20 feet closer to the batter. In addition, softball bats have significantly increased in performance and the

frequency of an optimal hit is much greater in softball than baseball. In this paper, we investigate the differences between composite-based and wood-based bats.

Background on Softballs: When slow-pitch softball became popular in the early 1970's, softballs were made of a cork, yarn or kapok center surrounded by a leather cover. However, over 95% of softballs available for purchase today have a solid polyurethane core surrounded by a well-bonded cover. A controlled laboratory test comparing softballs against baseballs was conducted (McDowell and Noebe, 2000) and indicated that current softballs can be over 120% harder than a collegiate baseball.

Background on Softball Bats: Up until the early 1970's, wooden softball bats were used almost exclusively in the sport of softball. In the 1980's, aluminum single-wall softball bats replaced wooden softball bats. In the 1990's, aluminum multi-wall bats replaced aluminum single-wall bats. In the late 1990's and early 2000's, bats made from titanium-based materials were introduced. From 2002 until today, composite-based materials comprise the majority of the softball bats used for all levels of play. In recent years, softball-related injuries and fatalities have been publicly reported (Dawson, 2003) with the majority of cases involving the combined use of composite-based softball bats and polyurethane softballs. Most of these injuries and fatalities could have been mitigated if injury risks associated with the sport of softball were available. A goal of this research is to provide this information to the general public.

An example of a catastrophic injury is shown in Figures 1, 2, and 3 in which the player suffered a catastrophic head injury after being struck by a batted-ball in a recreational softball game (Ohio). Eight plates, 32 screws and dozens of stitches/clamps had to be used to repair the damage. The player is now required to wear a protective helmet for many physical activities for the rest of his life.

Figure 1.
Example of a catastrophic head injury

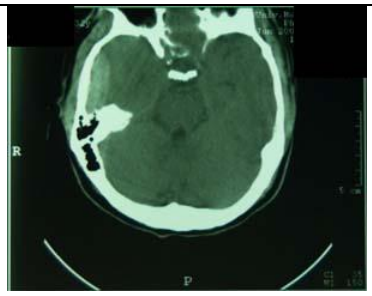

Figure 2.
X-Ray of catastrophic head injury

Figure 3.
Cranial reconstruction of catastrophic head injury

In another recent catastrophic injury shown in Figures 4 and 5, a player was hit in the face while defending a ball hit to the outfield and suffered an eye and head injury during a recreational softball game (Pennsylvania). The injury (called a ballistic impact by the attending physician) shattered his left lower orbital and broke and displaced his check bone, which required doctors to install two titanium plates in his face and a polyethylene sheet under his eye socket as well as three screws into the cheek bone to return it to and hold it in the correct position.

Figure 4. Example of severe eye injury sustained by an outfielder during a recreational softball game.

Figure 5. Close-up of severe eye injury sustained by an outfielder during a recreational softball game.

Figures 6 and 7 show an eye injury to a pitcher (Pennsylvania), where the pitcher was hit in the left cheekbone by a line drive. He stated that he had no time to react to the batted-ball. He suffered a fractured sinus cavity, a broken nose, the orbital bone of his left eye was broken above and below his eye, and the zygoma was broken. Surgery was required and two titanium plates were used to attach his orbital bones to stabilize the area and realign his zygoma. The lingering effects of this injury are intermittent left eye twitching and sinus infections.

Figure 6. Example of eye injury during sustained by a pitcher during a recreational softball game.

Figure 7. 3 days-post surgery of eye injury during sustained by a pitcher during a recreational softball game.

A softball player in Texas recently died from head trauma (The Associated Press, 2005) after being struck in the head by a thrown ball. We have also we have confirmed at least four additional fatalities in the sport over the past three years (Legal Pub, 2007) and (WSBT News, 2009). Each could have possibly been minimized or avoided completely if the league or tournament director knew the injury risks.

Table 1 lists selected web posts reporting injuries to players from being struck by either a batted or thrown ball. This list illustrates the seriousness of injuries that can result from a softball impact. Without reliable national injury statistics on the sport of slow-pitch softball, it is impossible to quantify the exact number of injuries and fatalities in slow-pitch softball due to ball impacts. However, one can speculate that the actual number of injuries is many times the number listed in Table 1.

By comparing the performance of current, state-of-the art composite softball bats against a traditional wooden softball bat as a baseline, we hope to shed light on the performance increases in the sport of softball. The significance of this research effort is to provide reliable experimental laboratory and field-test data on the safety risks to players that can potentially reduce serious, catastrophic and fatal injuries.

Table 1. Webposts of Injuries

Date	Player	Injuries	Link
7/5/09	Runner	Knocked out, Concussion, Hospital	http://www.softballfans.com/forums/showthread.php?t=662068
6/26/09	Pitcher	Skull Fracture	http://www.softballfans.com/forums/showthread.php?t=658183&highlight=prayer+wes
6/2/09	Runner	Skull Fracture	http://www.softballfans.com/forums/showthread.php?t=644891
5/17/09	Pitcher	Skull Fracture, ICU	http://www.softballfans.com/forums/showthread.php?t=634639
4/18/09	Runner	Death	http://www.softballfans.com/forums/showthread.php?t=618728
4/16/09	Pitcher	Fractured skull, Internal bleeding, Induced coma	http://www.softballfans.com/forums/showthread.php?t=617671
3/24/09	Runner	Skull fracture, ICU	http://www.softballfans.com/forums/showthread.php?t=603093
3/23/09	Pitcher	Two cracked ribs.	http://www.softballfans.com/forums/showthread.php?t=602569
9/24/08	Pitcher	Lost sight in one eye.	http://www.softballfans.com/forums/showthread.php?t=521918
6/18/08	Pitcher	Cracked skull, brain surgery, post #94	http://www.softballfans.com/forums/showthread.php?t=475221
5/19/08	Pitcher	Broken nose, fractured cheek	http://www.softballfans.com/forums/showthread.php?t=460102
5/19/08	Pitcher	Skull fracture, bleeding on brain, surgury	http://www.softballfans.com/forums/showthread.php?t=459776
4/18/08	Pitcher	Stitches and blurred vision	http://www.websitetoolbox.com/tool/post/911/vpost?id=2639642
12/20/07	Ump	Skull Fracture, multiple surgeries, Critical condition	http://www.b2g2.com/boards/board.cgi?action=read&id=1198329814&user=lonestarsoftball
11/6/07	Pitcher	Cracked skull, brain surgery, post #14	http://www.softballfans.com/forums/showthread.php?t=377803
11/4/07	Pitcher	Broken face bones, etc. Altered bat	http://forums.dssbats.com/sb/thread.cfm?threadid=4639&messages=79#279880
11/4/07	Pitcher	Broken nose and poss. face bones. Bat taken (#14)	http://www.softballfans.com/forums/showthread.php?t=376089
10/31/07	Runner	Brain swelling, memory loss	http://www.softballfans.com/forums/showthread.php?t=374990
10/28/07	Runner	Skull fracture, seizures, post #8	http://www.softballfans.com/forums/showthread.php?t=374990
10/18/07	Pitcher	Broken face bones, etc.	http://www.softballfans.com/forums/showthread.php?t=370640
10/4/07	Pitcher	Brain bleeding/swelling	http://www.softballfans.com/forums/showthread.php?t=371078
9/24/07	Pitcher	Post#23, lost his eye/skull fracture/broken cheek bone	http://www.softballfans.com/forums/showthread.php?t=362805
8/28/07	Runner	Skull fracture, plates installed	http://www.softballfans.com/forums/showthread.php?t=351962
8/27/07	Runner	Skull fracture, blood clots	http://www.softballfans.com/forums/showthread.php?t=351116
7/21/07	Pitcher	Fractured Orbital, Post Concussion Syndrome	http://www.softballfans.com/forums/showthread.php?t=391957
7/10/07	Runner	Skull fracture	http://www.softballfans.com/forums/showthread.php?t=331031
7/9/07	Pitcher	Lost an eye	http://www.softballfans.com/forums/showthread.php?t=330242
6/14/07	Pitcher	fractures to his cheekbone	http://www.softballfans.com/forums/showthread.php?t=320606
5/25/07	Pitcher	Broken fingers on the glove hand	http://www.softballfans.com/forums/showthread.php?t=312172
5/25/07	Pitcher	Blood clot in shin, moved to groin	http://www.softballfans.com/forums/showthread.php?t=311988
5/22/07	Pitcher	Skull fracture, sight impairment	http://www.softballfans.com/forums/showthread.php?t=310226
4/25/07	Runner	Skull fracture, internal bleeding	http://www.softballfans.com/forums/showthread.php?t=299261
3/1/07	Pitcher	Skull fracture, internal bleeding	http://www.softballfans.com/forums/showthread.php?t=274430
12/31/06	Pitcher	Broken kneecap	http://www.softballfans.com/forums/showthread.php?t=253810
12/20/06	Pitcher	Broken face bones	http://www.softballfans.com/forums/showthread.php?t=251238

12/7/06	Pitcher	35 stitches	http://www.floridasoftball.com/forum/showthread.php?t=4379
11/28/06	Runner	Brain swelling?	http://www.softballfans.com/forums/showthread.php?t=245766
11/16/06	Pitcher	nose split on both sides and facial fractures	http://vegas.softballjunky.com/viewtopic.php?t=2051
10/23/06	Ump	Bone bruise, bat to be tested, shaved?	http://www.floridasoftball.com/forum/showthread.php?t=4028 http://www.floridasoftball.com/forum/showthread.php?t=4021
9/13/06	Pitcher	Lost teeth	http://www.softballfans.com/forums/showthread.php?t=221885
8/22/06	1st base	Death, hit in chest w/ ball earlier?	http://www.softballfans.com/forums/showthread.php?t=213295
8/2/06	Pitcher	Upper jaw - Surgery	http://www.softballfans.com/forums/showthread.php?t=205086
7/24/06	Pitcher	Death	http://www.ourmidland.com/site/news.cfm?newsid=16959613&BRD=2289&PAG=461&dept_id=472542&rfi=6
7/10/06	Pitcher	Face, eye, cheek, orbital, teeth.	http://www.softballfans.com/forums/showthread.php?t=195509
5/15/06	Pitchers	Two cases, Skull Fracture / ?	http://www.softballfans.com/forums/showthread.php?t=174112
3/25/06	Pitcher	Possible lost hearing in one ear.	http://www.softballfans.com/forums/showthread.php?t=154519
3/6/06	Pitcher	Lost one eye and broken face bones	http://www.softballfans.com/forums/showthread.php?t=147444
2/15/06	Pitcher	Broken hand	http://www.softballfans.com/forums/showthread.php?t=140120
2/13/06	Pitcher	Lost teeth, post #14	http://www.softballfans.com/forums/showthread.php?t=138826
11/3/05	Pitcher	Broken kneecap	http://www.softballfans.com/forums/showthread.php?t=113630
11/2/05	Pitcher	Teeth knocked out	http://www.softballfans.com/forums/showthread.php?t=113162&highlight=pitcher+drilled
10/10/05	Pitcher	Broken jaw	http://www.softballfans.com/forums/showthread.php?t=108272
8/29/05	Runner	Fractured skull, Internal bleeding, ruptured eardrum	http://p076.ezboard.com/fslowpitchsoftballmohrsoftball.showMessage?topicID=42476.topic
8/8/05	Pitcher	Broken jaw and cheek	http://www.softballfans.com/forums/showthread.php?t=93290
7/4/05	Pitcher	4 stitches on face (SB12/Syn2)	http://www.softballfans.com/forums/showthread.php?t=83306&highlight=injured
6/20/05	Pitcher	Broken eye socket & 30 stitches	http://www.softballfans.com/forums/showthread.php?t=79196&highlight=injured
5/29/05	Pitcher	Broken jaw and cheek	http://www.softballfans.com/forums/showthread.php?t=72810&highlight=injured
5/16/05	Pitcher	Reconstructive surgery, vision trouble	http://www.softballfans.com/forums/showthread.php?t=68990&highlight=injured
4/4/05	Runner	Broken eye socket, skull fracture, broken rib, etc.	http://www.softballfans.com/forums/showthread.php?t=57734&highlight=injured
3/29/05	Fan, 4yrs	Cracked skull, coma	http://www.softballfans.com/forums/showthread.php?t=56255&highlight=injured
2/14/05	Pitcher	Bruised head, OK	http://www.softballfans.com/forums/showthread.php?t=46145&highlight=injured
11/15/04	Pitcher	Hit in forehead?	http://www.softballfans.com/forums/showthread.php?t=32506&highlight=injured
10/12/04	Pitcher	Lost an eye	http://www.softballfans.com/forums/showthread.php?t=28496&highlight=injured
8/24/04	Pitcher	Broken leg	http://www.softballfans.com/forums/showthread.php?t=23173&highlight=injured
7/29/04	Pitcher	Cracked sinus cav., 12 stitches	http://www.softballfans.com/forums/showthread.php?t=20175&highlight=injured
7/23/04	Pitcher	Bad leg bruise (male batter female pitcher)	http://www.softballfans.com/forums/showthread.php?t=19548&highlight=injured

This study of softball injury risk is comprised of two parts. Part 1 was an indoor controlled study analyzing Batted-Ball Velocities (BBV) using composite-based and wood-based softball bats. Part 2 was a controlled outdoor study analyzing distance data using composite-based and wood-based softball bats. For these comparison parts of this study, over 250 batted-ball velocity measurements and over 200 distance measurements were recorded. The softball model was compression tested according to the ASTM ball compression standard (ASTM F1888-02, 2002) and has a compression value of 2576 +/- 78.7 N/0.64 cm. All five bat models were 857 g in weight and were certified and approved by either the United States Specialty Sports Association (all five bat models) and/or the Amateur Softball Association of America (three bat models). All softball bats and balls were purchased from retail sporting goods stores. We used five adult male softball players in Part 1 of this study; 4 of these 5 players were used in Part 2 of the study. What follows is a description of each part of the study.

Indoor Batted-Ball Velocity Study:

We chose five male bat testers with each bat testers having at least six years of league and tournament playing experience. Each bat tester was required to hit two rounds of five line drive hits each for a total of ten recorded batted-ball velocity measurements for each bat tester. A five-minute rest period between each round was required in order to mitigate fatigue. To minimize bias and ensure accurate testing, all recorded line drive hits were factored into the analysis in order to get a true performance metric.

Pitching Machine: A Jugs™ softball pitching machine was used to accurately pitch a softball between 7 and 10 m/s. This range was used to represent the average pitch speed a typical batter will

experience in a softball game. The arc height of the pitched balls was between 1.5 and 3 meters from the ground.

Batted-Ball Velocity Measurements: A Stalker Sport™ radar device was used to record batted-ball velocity measurements. The Stalker Sport™ radar device is accurate to within +/- 0.16 km/hr and has a target acquisition time of 0.046 seconds. The radar gun was mounted on a tripod 1.5 m from the ground facing the batter approximately 24 m away. Figure 8 shows the setup used for the indoor testing. Using the fact that the target acquisition time for the radar gun is 0.046 seconds, we calculated the Initial Batted-Ball Velocity (IBBV) by taking into account ball deceleration due to air resistance (Adair, 1997). The calculation for initial batted-ball velocity is as follows:

$IBBV = V_{radar} + (0.0001554*(V_{radar})^2 - 0.01417*(V_{radar}) + 1.06),$ **Eq. (1)**

where V_{radar} is the measured value from the radar gun in mph.

Outdoor Distance Study:

We used four out of the five male testers from the indoor study (the 5th tester was unable to participate). Each bat tester was required to hit two rounds of five distance hits each for a total of ten recorded distance hits for each bat tester. A minimum, five-minute resting period between each round was required in order to mitigate fatigue. To minimize bias and ensure accurate distance testing, all recorded distance hits beyond 285 feet were factored into the analysis. Ground balls, pop-ups and line drives were excluded from the distance data.

Distance Measurements: Accurate distance measurements were taken with two Bushnell Yardage Pro™ laser range finder devices. Distance readings were taken from the batter to the point where the ball initially landed to ensure consistent readings. The distance data measured up to 10 distance

hits for each batter with each bat. Only balls that landed 285 feet or farther were counted for composite-based bats and only balls that landed 270 feet or farther were counted for wooden bats.

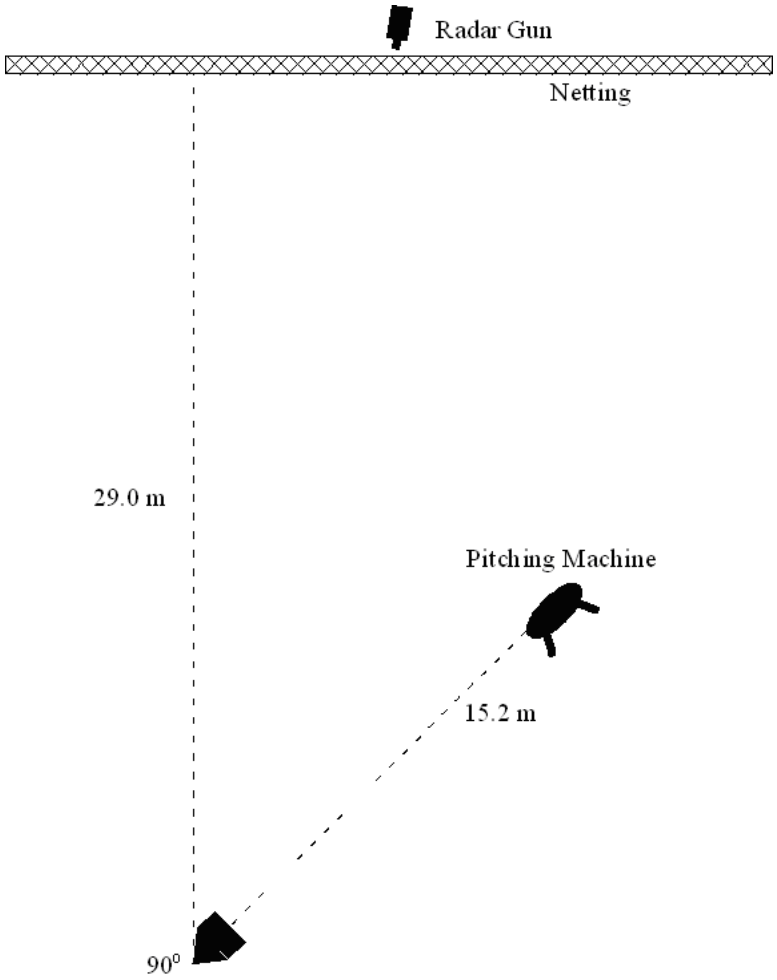

Figure 8. Controlled Indoor Field Testing Setup

RESULTS

The batted-ball velocity data were grouped into three categories for analysis; all data, top 30% (Used to represent an "optimally-struck" ball) and high-low values. This was done in order to statistically validate the data to ensure the results were significant.

Table 2 lists the IBBVs of all data and shows that, on average, IBBVs using composite bats were 97.0 mph and the average for the wooden bat was 85.4 mph, representing a 13.6% difference in performance. Using all of the data as a metric, composite bats resulted in softball speeds 11.6 mph faster than for wooden bats.

In order to represent an optimally-struck ball, we chose to analyze the top 30% of the IBBV data. Table 3 lists the IBBVs of the top 30% of the data and shows that, on average, IBBVs using composite bats were 99.5 mph and the average for the wooden bat was 87.2 mph, representing a 14.1% increase in performance. Using the top 30% of the IBBV data, composite bats were 12.3 mph faster than softball hit by wooden bats.

Table 2. ALL IBBV DATA (100%)

	BT1	**BT2**	**BT3**	**BT4**	**BT5**	**Comp Avg**
Comp1	101.8	101.2	92.9	97.3	100.9	98.8
Comp2	98.4	97.6	91.6	94.8	93.7	95.2
Comp3	95.4	99.1	90.6	93.1	94.1	94.5
Comp4	99.9	103.7	94.9	97.7	101.9	99.6
BBV Avg	98.9	100.4	92.5	95.7	97.6	97.0
Wood	86.5	86.1	81.2	86.3	86.7	85.4

Table 3. Top 30% IBBV Data

	BT1	BT2	BT3	BT4	BT5	Comp Avg
Comp1	104.6	104.2	95.1	100.2	104.2	101.7
Comp2	100.2	99.9	94.1	96.1	95.8	97.2
Comp3	98.1	100.2	93.1	95.1	96.1	96.5
Comp4	103.9	106.3	96.1	99.9	106.6	102.6
BBV Avg	101.7	102.6	94.6	97.8	100.7	99.5
Wood	89.7	88.0	81.9	87.3	89.0	87.2

Table 4 lists the distance data and shows that, on average, distance measurements using composite bats was 351.4 feet and the average for the wooden bat was 296.3 feet, representing an 18.6% increase in performance. The use of the composite bats resulted in hits that were 55.1 feet farther then the comparable hits using wooden bats. The distance data using composite bats ranged from a low of 285 feet to a high of 420 feet. Using the wooden bat, the distance data ranged from a low of 270 feet to a high of 336 feet.

Table 4. All Distance Data (100%)

	BT1	BT2	BT3	BT4	All Avg
Comp1	352.3	379.3	354.6	369.8	364.0
Comp2	332.3	373.1	325.2	337.9	342.1
Comp3	327.0	348.4	319.2	339.8	333.6
Comp4	370.8	379.5	342.4	371.5	366.1
Dist Ave	345.6	370.1	335.4	354.8	351.4
Wood	286.5	315.6	288.0	295.0	296.3

DISCUSSION

This study demonstrated that composite-based bats consistently resulted in batted-ball velocities that exceeded recommended published safety metrics, while wooden bats resulted in batted-ball velocities that were within these metrics. More specifically, based on published injury reports as well as the batted-ball velocity measurements in the paper, it is clear that the use of composite bats along with polyurethane balls poses a significant safety risk in the sport of softball. By relying on recommended published safety metrics (Mississippi State University, 2002) and (Nicholls, et al., 2003) for initial ball exit speed, we are able to compare our results effectively. Based on the results obtained in this paper, composite bat far exceed the recommend published safety metrics. We used a maximum initial batted-ball velocity of 41.6 m/s (93 mph) as a comparison safety metric in this study based on the two baseball safety studies aforementioned. All of the bat testers were able to exceed the 93 mph safety metric using composite bats but none of the bat testers were able to exceed it using wooden bats.

Another safety metric to consider is reaction time of the nearest player on the field, the pitcher. A reaction study conducted by Owings, (Owings, et. al., 2003) looked at the reaction times of various youth age groups. For the oldest age group studied, 16 year olds, they concluded that at least 0.409 seconds was necessary to reduce the potential for serious or catastrophic injury. This equates to an initial batted-ball velocity of 39.0 m/s (87.2 mph), which is significantly slower than the velocities measured in our study. This study focused on younger players, which do not accurately represent the older population that plays the majority of recreational softball. It has been shown that older adults have slower reactions than younger adults (Hultsch, et al., 2002 and Luchies, et al., 2002).

This study was conducted to highlight the current, state-of-the-art softball bats and show that the sport of softball can be unreasonably dangerous when composite-based softball bat are used along with polyurethane softballs. We recommend that leagues and tournaments avoid using composite-based softball bats in combination with polyurethane softballs. This change in protocol should bring the softball leagues into compliance with recommended published safety standards.

CONCLUSION

The use of high-tech composite softball bats combined with polyurethane softballs produced batted-ball velocities that exceed "safe" recommended initial batted-ball velocities. On average, when compared to a wooden control bat, the batted-ball velocities using composite bats exceeded the performance of wooden bats by over 13%. Distance measurements using composite softball bats exceeded the performance of wooden bats by over 18%.

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This study is dedicated to the late Dr. Richard Zeller…

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