ABSTRACT

ROLE OF MATERIAL & DESIGN ON PERFORMANCE OF BASEBALL BATS

by Kim Benson-Worth

Baseball bat safety has become an increasing area of interest with more than 19 million people in the United States alone participating in this sport. An increase in injuries resulting from bat injuries has brought the performance of the bats into question. A review of several studies focusing on the effects of the material properties of various baseball bats designs were examined. From this review it is evident that player and spectator safety greatly rely on proper baseball bat design. There was a 30% reduction in the Multi-Piece Failures (MPF) of wooden bats once the requirement of a Slope of Grain (SOG) of 1:20 or 3 degrees was introduced in 2009. Further research into the implications of material and design can only help increase the safety to players and spectators.

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by
Kim Benson-Worth

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ROLE OF MATERIALS & DESIGN ON PERFORMANCE OF BASEBALL BATS

Kim Benson-Worth

Dr. N.M. Ravindra, Thesis Advisor — Date
Chair of Physics, NJIT

Dr. Keun Hyuk Ahn, Committee Member — Date
Assistant Professor of Physics, NJIT

Dr. Anthony T. Fiory, Committee Member — Date
Research Professor of Physics, NJIT

Mr. Peter Kaufman, Committee Member — Date
President and Chief Technical Officer, PSS Inc.

BIOGRAPHICAL SKETCH

Author: Kim Benson-Worth

Degree: Masters of Science

Date: January 2013

Undergraduate and Graduate Education:

- Master of Science in Materials Science and Engineering,
  New Jersey Institute of Technology, Newark, NJ, 2013
- Bachelor of Science in Mechanical Engineering,
  New Jersey Institute of Technology, Newark, NJ, 2001
- Associate of Science in Mechanical Engineering,
  Brookdale Community College, Lincroft, NJ 1998

Major: Materials Science and Engineering

This thesis is dedicated to my husband Daniel Worth. It was his love and support that gave me the ability to complete this work.

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TABLE OF CONTENTS

TABLE OF CONTENTS

Chapter **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ABI	Accelerated Break-In
BBCOR	Bat-Ball Coefficient of Restitution
BBS	Batted Ball Speed
BES	Ball Exit Speed
BESR	Ball Exit Speed Ratio
BEV	Ball Exit Velocity
BRC	Baseball Research Center
COR	Coefficient of Restitution
MLB	Major League Baseball
MOI	Moment of Inertia
MPS	Multi-Piece Failure
NAPBL	National Association of Professional Baseball League
NCAA	National Collegiate Athletic Association
NFHS	National Federation of State High School Association
SOG	Slope of Grain
SPF	Single Piece Failure

INTRODUCTION

1.1 Objective

Baseball is known as America's favorite past time. Its history can be traced back as far as the 1700's. As a sport with such longevity, it has gone through many revisions to method of play and equipment used. One of the most important elements to the game of baseball is the baseball bat.

Over the history of the game of baseball there have been many changes. One of the changes is that of the formation of leagues. Baseball on the whole can be broken into the three distinct leagues, Major, Minor and Little League. Each of these leagues has its own rules governing equipment used, field dimensions and bat performance ratings

The purpose of this study is to examine baseball bat safety. There have been many recorded instances of player, spectator and umpire injuries attributed to baseball bat failure of one kind or another. This study will look at the various types of baseball bats available, their design and their performance ratings. It will also investigate whether field dimensions of Major, Minor and Little League fields have a contributing factor to injuries.

1.2 Baseball Bat Evolution

In the early days of baseball, any wooden stick would serve as a bat. But as the game gained popularity, leagues were formed and from that grew the need for a more formalized method of play. The equipment used to play baseball also needed to have a set standard.

Baseball bat standards were introduced in 1857 at the first baseball convention [1] and continue to be modified to this day. Figure 1.1 is an example of available wood bats for 1875. The bats are advertised as meeting regulation requirements.

Baseball bat types and the rules governing them have undergone several revisions throughout the years. Today each league has its own baseball bat regulation on material, length, dimension and performance. Each leagues' regulation for the 2012 season will be investigated and how those regulations impact baseball bat safety will be explored.

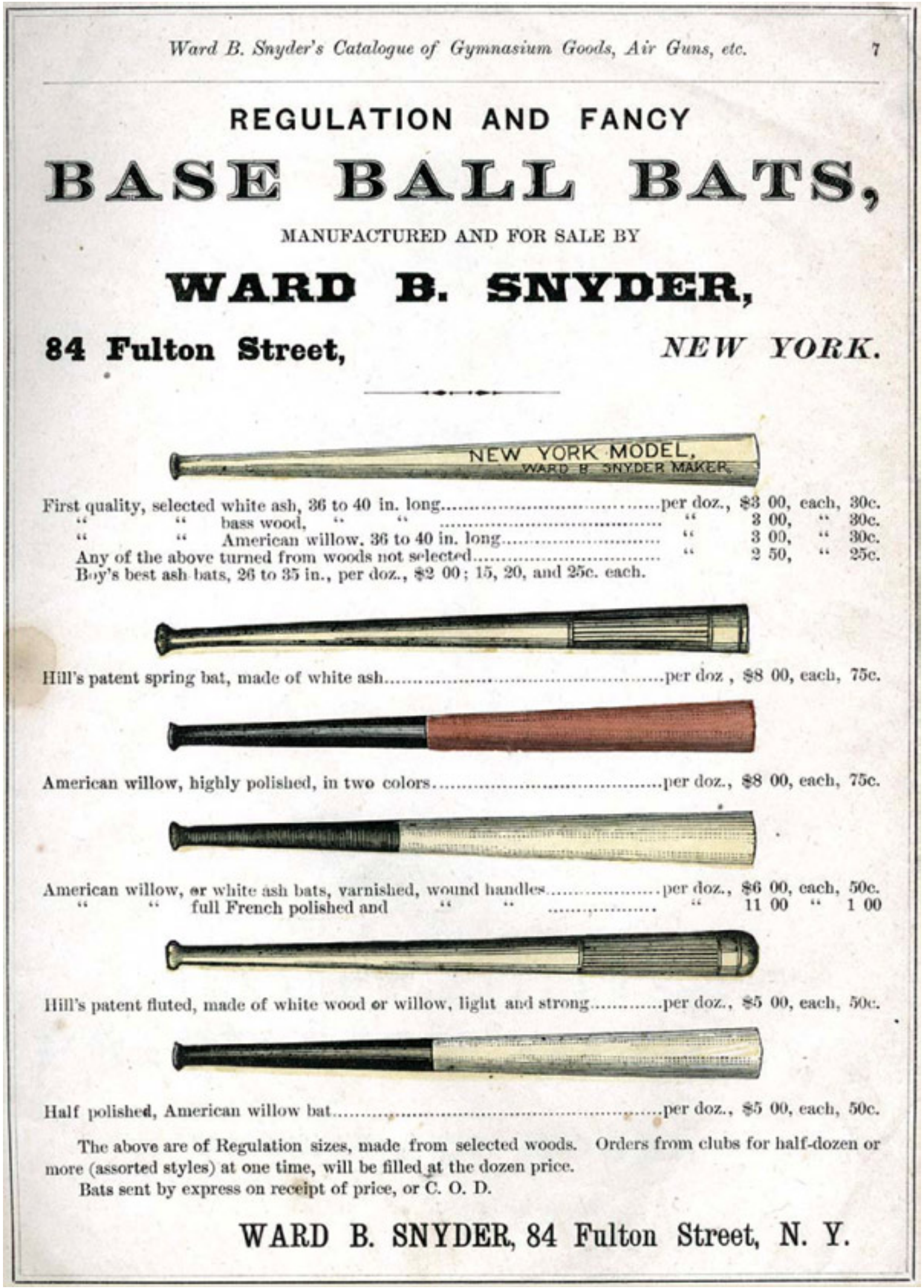

Figure 1.1 Shows an 1875 Baseball Bat advertisement from the Ward B. Snyder manufacturing company. It emphasizes that the bats are *Regulation* make. [2].

1.2.1 Major and Minor League Baseball Bat Regulations

Taken from the Official Baseball Rules; Rule 1.10 [3] governs baseball bats allowed for use in professional Major League Baseball (MLB) and National Association of Professional Baseball Leagues (NAPBL), which comprises the Minor League Baseball teams:

a) The bat shall be a smooth, round stick not more than 2.61 inches in diameter at the thickest part and not more than 42 inches in length. The bat shall be one piece of solid wood.

   NOTE: No laminated or experimental bats shall be used in a professional game (either championship season or exhibition games) until the manufacturer has secured approval from the Rules Committee of his design and methods of manufacture.

b) Cupped Bats. An indentation in the end of the bat up to 11/4 inches in depth is permitted and may be no wider than two inches and no less than one inch in diameter. The indentation must be curved with no foreign substance added.

c) The bat handle, for not more than 18 inches from its end, may be covered or treated with any material or substance to improve the grip. Any such material or substance that extends past the 18-inch limitation shall cause the bat to be removed from the game.

   NOTE: If the umpire discovers that the bat does not conform to (c) above until a time during or after which the bat has been used in play, it shall not be grounds for declaring the batter out, or ejected from the game. Rule 1.10(c) Comment: If pine tar extends past the 18-inch limitation, then the umpire, on his own initiative or if alerted by the opposing team, shall order the batter to use a different bat. The batter may use the bat later in the game only if the excess substance is removed. If no objections are raised prior to a bat's use, then a violation of Rule 1.10(c) on that play does not nullify any action or play on the field and no protests of such play shall be allowed.

d) No colored bat may be used in a professional game unless approved by the Rules Committee.

While Major League Baseball requires the bat to be one piece of solid wood, it does not specify the type of wood or weight. Wood baseball bats have traditionally been made of White Ash. However, in recent history, Sugar Maple, Yellow Birch and Hickory have also been employed. Herein lies the speculation that a Maple bat has a greater tendency to fail over an Ash bat. The question has also been raised as to whether the new manufacturing methods have increased baseball bat failures.

1.2.2 Little League Baseball Bat Regulation

Much like Major League Baseball, Little League Baseball also has a Rule 1.10 [4] governing the baseball bat specification. The only exception here is that Little League Baseball is comprised of multiple age group division. Therefore, the rules governing bat regulations change as the child advances in age. Rule 1.10 for Little League play states: the bat must be a baseball bat which meets Little League specifications and standards as noted in this rule. It shall be a smooth, rounded stick and made of wood or of material and color tested and proved acceptable to Little League standards. The Little League divisions and their respective bat regulations are as follows:

a) **Little League (Majors) and below:** it shall not be more than thirty-three (33) inches in length nor more than two and one-quarter (2¼) inches in diameter. Non-wood bats shall be labeled with a BPF (bat performance factor) of 1.15 or less;
b) **Junior League**: it shall not be more than 34 inches in length; nor more than 2 5/8 inches in diameter, and if wood, not less than fifteen-sixteenths (15/16) inches in diameter (7/8 inch for bats less than 30”) at its smallest part. All composite bats shall meet the Batted Ball Coefficient of Restitution (BBCOR) performance standard, and such bats shall be so labeled with a silkscreen or other permanent certification mark. The certification mark shall be rectangular, a minimum of a half-inch on each side and located on the barrel of the bat in any contrasting color.
c) **Senior/Big League**: it shall not be more than 36 inches in length, nor more than 2 5/8 inches in diameter, and if wood, not less than fifteen-sixteenths (15/16) inches in diameter (7/8 inch for bats less than 30”) at its smallest part. The bat shall not weigh, numerically, more than three ounces less than the length of the bat (e.g., a

> 33-inch-Iong bat cannot weigh less than 30 ounces). All bats not made of a single piece of wood shall meet the Batted Ball Coefficient of Restitution (BBCOR) performance standard, and such bats shall be so labeled with a silkscreen or other permanent certification mark. The certification mark shall be rectangular, a minimum of a half-inch on each side and located on the barrel of the bat in any contrasting color. Aluminum and composite bats shall be marked as to their material makeup being aluminum or composite. This marking shall be silkscreen or other permanent certification mark, a minimum of one-half-inch on each side and located on the barrel of the bat in any contrasting color.

As can been seen from these rules, Little League Baseball allows bats made from materials other than wood. Acceptable baseball bat types are wood, alloy/metal, composite and hybrid or half and half bats. And these bats must meet BBCOR, a bat performance rating which will be discussed later.

1.3 Field Dimensions

In regard to baseball bat safety, field dimensions must be considered. The time of ball travel from pitcher to hitter is a function of the distance between them. Therefore the pitcher reaction time to a bat that has split off is also a function of that distance. But it's not just the pitcher who is at peril. There have been numerous accounts of runners, basemen, umpires and even spectators who have been injured by a piece of flying bat. Figure 1.2 shows the field specification of a Major League Baseball field. Lovingly called a baseball diamond due to its shape, its form has remained constant through the years.

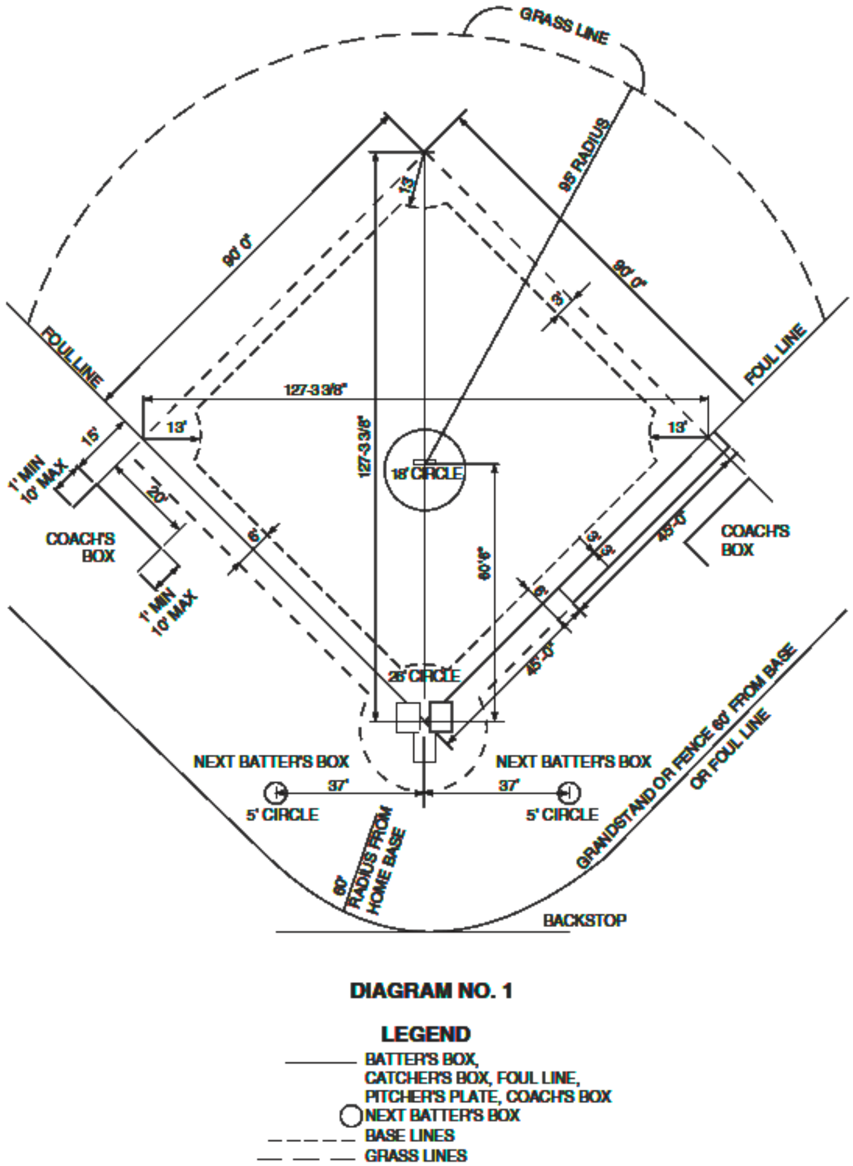

Figure 1.2 Field specifications of a Major League Baseball Field.
[3]

In a Little League baseball field the dimensions are approximately 2/3 of that of a Major League field. This reduced distance also reduces the reaction times for the players. The shorter distances and the more varied use of baseball bat type has forced Little

League Baseball to enforce greater regulations on the performance factor a bat can have. Figure 1.3 below shows the field dimensions for a Little League field.

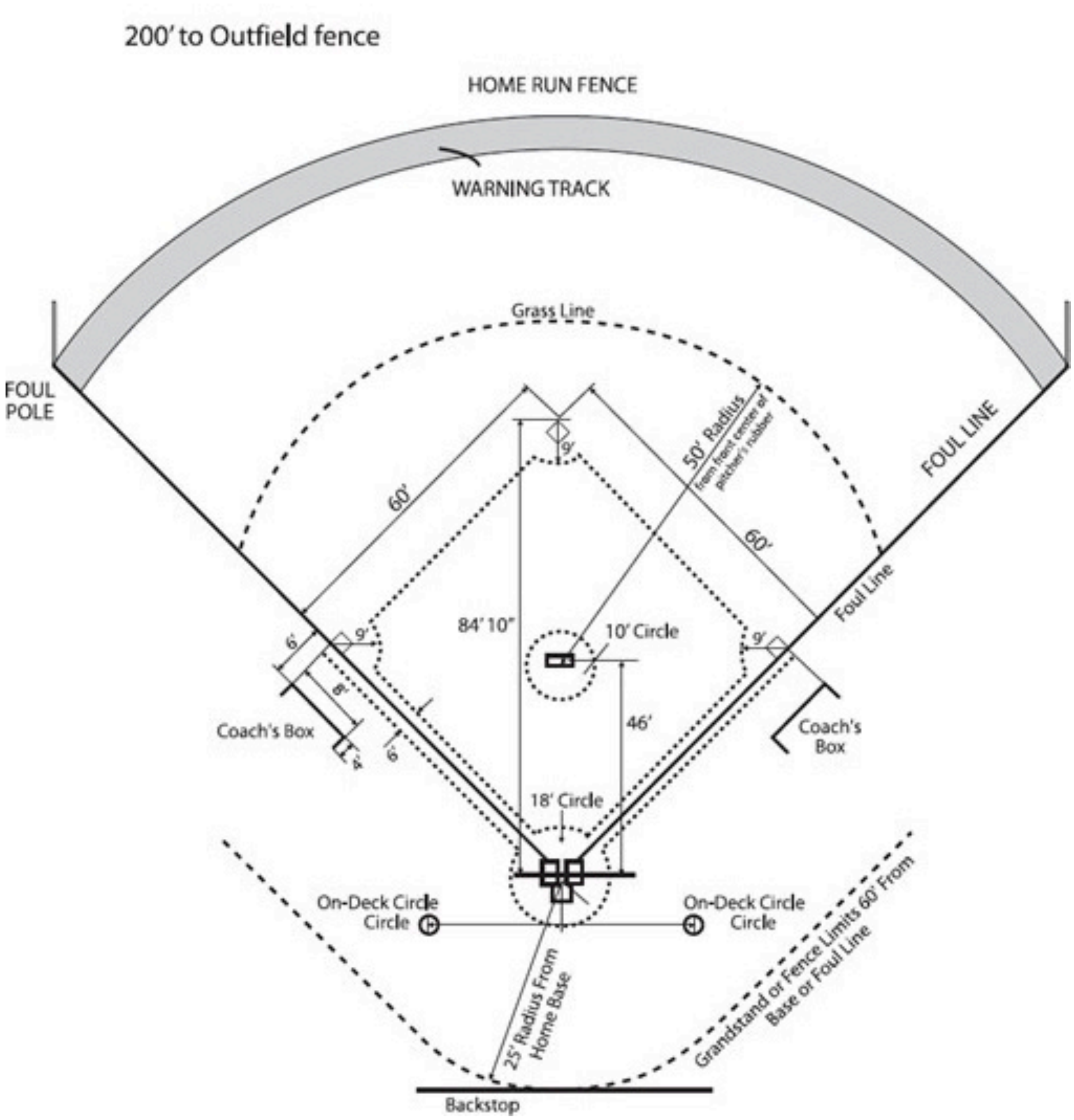

Figure 1.3 Field specifications of a Little League Baseball Field.
Source: [5]

1.4 Bat Compositions

As mentioned earlier, when it comes to baseball bat types, Little League players are allowed to use wood, alloy/metal, composite or hybrids. Major and Minor players are restricted to wood bats only. This is because it has been proven that baseball bats not made solely of wood can give a player an advantage. To negate this advantage, the professional leagues (ones where players are paid) instituted the wood only rule to keep the game fair. But the non-professional leagues are free to take advantage of the benefits of other bat models.

The accepted wood baseball bat standard for Major League Baseball is the Northern White Ash. Its material characteristics make it the wood bat of choice for players through the history of the game. White Ash is a “ring porous” wood species, “Which means during each year of the trees growth there are clear concentrations of large early wood cells, and then an abrupt transition to smaller latewood cells” [6]. Figure 1.4 shows an example of ring porous White Ash.

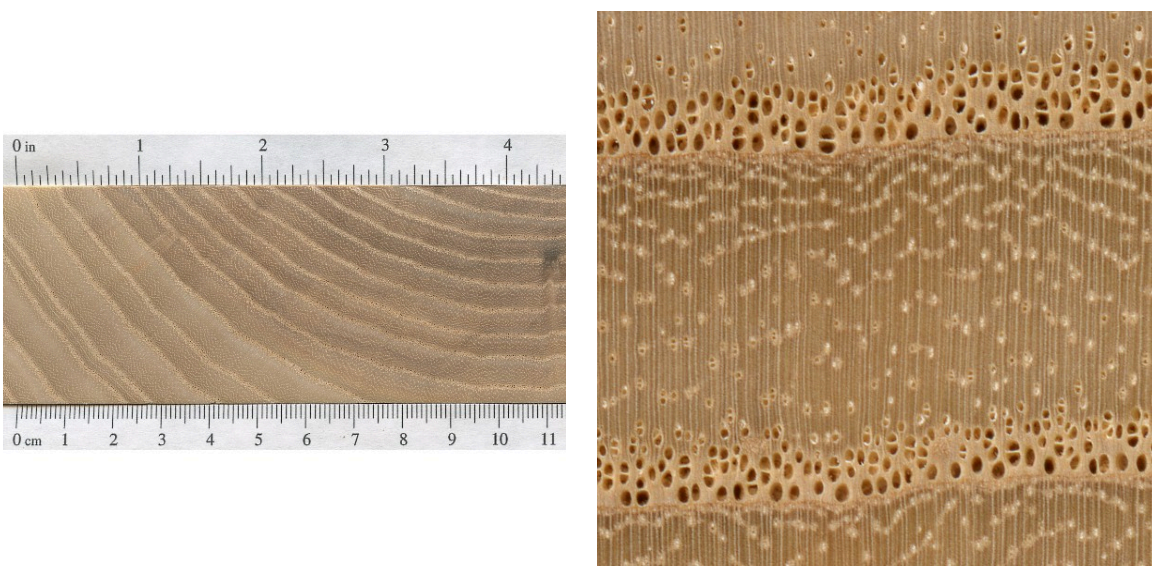

Figure 1.4 Ring porous White Ash, edge grain. Picture on right magnified 10x. [7]

White Ash also has a good specific gravity rating or in simpler terms a good weight to it. This enables the barrel to be larger than that of a heavier more dense wood such as Sugar Maple. It also has greater flexibility; meaning when struck it will bend rather than break. That is not to say an Ash bat cannot fail. On the contrary, Ash bats must be held in a specific way when used. Failure to do so will cause the bat to fail.

Due to its ring porous nature, attention must be paid to the two types of grains present. They are edge-grain face and flat-grain face. Edge-grain face, as the name suggest, is the part of the bat where the edges of the grains on the bat are to be placed perpendicular to the ball. Many baseball bat manufacturers will place their logos on the flat-grain face to aid players in knowing where the edge is. If a ring porous bat is held with the flat-grain face perpendicular to the ball, the bat may fail by flaking after repeated uses. This is known as annual ring separation.

Figure 1.5 Broken White Ash bat on flat-grain face. [6]

The Sugar maple baseball bat has come in to recent popularity with major league players. Some players feel it is a more solid bat. To that end, they are on the right track. A maple bat is denser than an ash bat and it does not flex as much as an ash bat when struck. However, since its introduction in the early 2000's bat failure incidents have increased. This sparked the MLB to perform an investigation on the sudden increase in incidents.

Maple baseball bats are a different wood species. Their growth pattern is of a diffused porous nature, "Which means that it has a more even density of similar-size wood cells across the growth ring" [6]. Figure 1.5 shows an example of diffused porous Hard Maple.

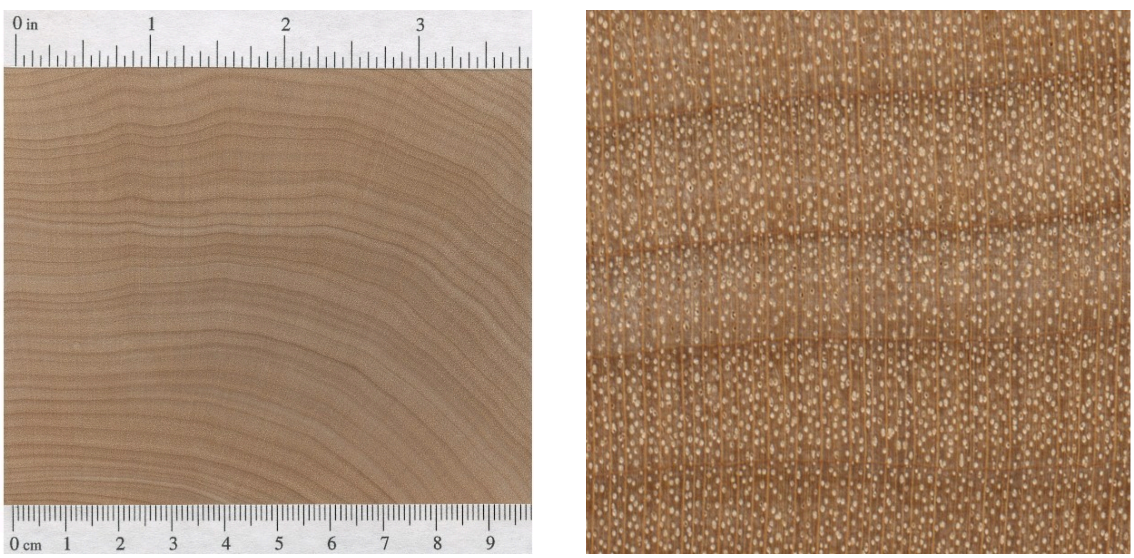

Figure 1.6 Diffused porous Hard Maple, edge grain. Picture on right is magnified 10x. [7]

Due to the wood cells being of similar size, delineation between growth stages as in an Ash species does not exists. Therefore, Maple bats do not suffer from annual ring separation as their Ash counterparts do. Maple bats do still have edge-grain face and flat grain face but it is not necessary to strike the ball on the edge grain face; a maple bat is strongest on its flat -grain face. In truth, wood science has shown that the flat-grain face is the strongest in regard to impact bending for all wood species. But for ring porous species, repetitive impact can cause annual ring separation so the edge-grain face must be used.

Table 1.1 Shows the Mechanical Properties of Various Wood Species. [8]

Tree Species	Average Specific Gravity, Oven Dry Sample (0-1.0)	Static Bending Modulus of Elasticity (10^6 psi)	Impact Bending, Height of Drop Causing Failure (inches)	Shear Parallel to the Grain Max Shear Strength (psi)
Hickories	0.71	2.06	74	2,100
Yellow Birch	0.62	2.01	55	1,880
Ash, White	0.60	1.74	43	1,910
Maple, Sugar	0.63	1.83	39	2,330

Table 1.1 was created by the Society for American Baseball Research as an illustration of how various baseball bats perform mechanical to each other. When taking a closer look at the Ash bat versus the Maple bat, it can be seen that there exists subtle differences between them but these difference have everything to do with how they fail. As mentioned before, an Ash bat has a greater impact strength compared to a Maple bat and is lighter. Meaning it is less likely to break at the handle as Maple bats do. When an Ash bat fails, it's usually of the Single Piece Failure (SPF) not a Multi-Piece Failure (MPF) type, which is typical of Maple bats. Mechanical properties, design and failure type will be discussed further in later chapters.

The discussion to this point has focused on wooden bats only. But as most people know baseball bats can be metal as well. Not only can some baseball bats be metal, they can be composite. These types of bats are used in Little League and scholastics sports programs. Figure 1.6 is an illustration of these other forms of baseball bats.

Figure 1.7 Illustration of bat compositions. [9]

The primary alternate baseball bat types for the Little League are Aluminum and composite. The main reason these bat types are allowed is that they are more cost effective (metal and composite bats have a longer usage life), they can be manufactured to outperform their wooden counterpart and they can weigh less so it's easier for a young player to swing the bat.

Composite baseball bats have been around almost as long as baseball itself. The very first composite bats were "corked" wood bats. Major League Players would hollow out their bats and fill them with cork to make them lighter and easier to swing. This, however, was in direct violation of the rules and players who were caught were punished.

Aluminum baseball bats didn't make their entrance on to the field until the 1970's. It took that long to come up with the right manufacturing methods to make the bats lighter. When first introduced, there were no standards of performance. Players of all types quickly found out that an aluminum bat had a great advantage over a wooden bat. Players could see that they would hit the ball farther when using the metal bat. The MLB has always used wood bats and continues to do so in the belief that the players' skill is what should win games. The National Collegiate Athletic Association (NCAA) is also now considering a ban on metal and composites bats for the same reason and also due to injuries reported from use of metal or composite bats.

So what exactly constitutes an aluminum baseball bat? Today, most baseball and softball bats that are referred to as aluminum are actually some mix of an aluminum alloy. The primary element is aluminum but other elements such as zinc and magnesium are added in to yield better durability and performance. However, due to recent safety concerns, any metal or composite bat that is to be used must meet the specified Batted Ball Coefficient of Restitution (BBCOR) and have its' rating and composition types on the bat.

Table1.2 Shows Mechanical Properties of the Most Commonly used Aluminum Baseball Bats. [10,11]

Aluminum Alloy	**Specific Gravity**	**Modulus of Elasticity GPa**	**Tensile Strength (Yield) GPa**
AA7046	2.82	69-79	N/A
CU31/AA7050	2.83	71.7	469
C405/AA7055	2.86	72	614

The main safety concern with metal bats is not just MPF. While it is possible for metal bats to break, it's a rarity. The performance of the bat itself is the issue. Metal bats have the ability to release almost all of the energy from the bat ball collision back to the ball [12]. So in the case of a line drive directed back to the pitcher, the pitcher has little time to respond and can be hit by a ball traveling it 98mph (44m/s). This is especially dangerous for the little league players where the field dimensions are smaller.

CHAPTER 2

REVIEW OF PREVIOUS STUDIES

2.1 Introduction

Over the last decade, there has been an increase in studies focusing on baseball bat safety. This has come as a result of an increase in wood bat failures and injuries sustained to players by balls hit with metal bats. A study performed by Mueller and Marshall in 2007 illustrated the injuries sustained by youth players of National Collegiate Athletic Association (NCAA) teams. They specifically investigated injuries sustained from line drives directed to the pitcher from the type of bat used. Over the course of their study, they discovered a college pitcher was three times more likely to be injured by balls in play hit by a metal bat.

Per Nicholls, Elliott and Miller (2004), over 19 million people are part of an organized baseball or softball league in the United States. Of those people, the majority of players are children and young adults who use metal bats. Hence the injuries sustained that are affiliated with metal bats are to these children and young adults. In their study, they point out that more children in the 5- to-14 year range have died as a result of an impact to the chest. And in the 51 deaths reported in 1973-85, 41% were due to chest impacts by the ball. But in Major League Baseball wooden bats are used exclusively. The risk of bat injury in a MLB game extends to players and spectators.

There have been numerous recorded instances in the past few years of wooden bats flying apart into lethal projectiles. This increase has been linked to the recent upsurge in the use of maple baseball bats. That is not to say that the traditional Ash baseball bat do not fail, but it does not fail as dramatically. A 2005 Baseball Research

Center (BRC) showed that maple bats are three times more likely to have a MPF over their ash counterparts. In 2008, the MLB's Safety and Health Advisory Committee conducted their own tests and confirmed the 2005 BRC findings.

Up until 1998, the NCAA didn't discriminate between injuries sustained from metal bats versus wood. But when the injuries became more life threatening, an investigation was launched. This chapter will be devoted to studies that illustrate metal bat and wood bat safety issues.

2.2 Metal Bat Safety Studies

In youth group baseball or softball, metal bats prevail; therefore in recent years there have been many studies on the performance of metal bats versus their wood counter parts. The argument being that metal bats out perform wooden bat, an argument that has been proven in several studies. Nicholls, Elliott and Miller [13] argue that the Ball Exit Velocity (BEV) is a key feature to understanding the difference in baseball bat performance. In baseball, the goal is to have the ball leave the bat at its highest possible velocity. A high BEV gives the hitter an advantage, but in doing so there is an increase risk of injury to the defending team. From their research, they correlated an increase in chest impact injuries from 2.1 per year for the years 1973-1980 to 3.3 in the years from 1980-1990. This increase, they argue, is attributed to an increase use of the lighter and better performing metal baseball bats.

Strictly examining the BEV of metal bats to wooden bats showed a stark increase in the exit velocity of balls hit by metal bats. One study showed the BEV for wooded bats at 39.4 m/sec and 41.1 m/sec for metal bats. Another had the BEV for wooden bats at 43.8 m/sec and 45.8 m/sec for metal bats. As it can be seen, there is at least a 2 second difference between the two material types, which if you are a pitcher could mean the difference in being able to react quick enough to protect yourself. In a study performed by Cassidy and Brown, they calculated response time that the pitch would need is minimum of 400ms to protect themselves [13]. This translates to a safe Ball Exit Velocity of 93mph (42m/s). In impact injury studies of the head, fracture has been shown to happen at just 58 mph (26 m/s). A study by Greenwald, Penna and Crisco (2001) had high school players attaining BEV values of 99mph (160km/hr) when using metal bats [14].

Table 2.2 Comparisons of BEV Studies [12, 14,15] for Wooded Bats vs. Metal Bats

Study	BEV Wood Bat m/sec (mph)	BEV Metal Bat m/sec (mph)
Bryant et al.	39.4 (88.1)	41.1 (91.9)
Greenwald et al.	43.8 (97.9)	45.8 (102.4)
Nicholls et al.	40.8 (91.2)	44.0 (98.4)

Other inherent properties of metal baseball bats are its Moment of Inertia and its “trampoline affect”. It has been postulated by Nicholls et al. [13] that these factors play a major part in metal bats performing better. And since these bats can perform better, a wider range of injuries is sustained. For example, the barrel of a metal bat can be larger than a barrel of a wooden bat and still be easy to swing at a faster rate due to it having a more uniform weight distribution. Whereas, the weight distribution of a wooden bat creates a heavier barrel, thus take longer to swing. This will affect the BEV. The metal bat will maintain a higher BEV over the wooden bat.

2.3 Wood Bat Safety Studies

Wooden baseball bats are the only baseball bats allowed in professional Major League Baseball. They are allowed in the Little, High School and Collegiate leagues, but due to their expense and life expectancy, they are not typically employed. The majority of reported injuries from wooden bats are in MLB games. A wood bat injury could consist of a line drive to an infielder or it could be a piece of a broken bat hurtling off into the stands at some unsuspecting fan.

As a sport with over 150 years of history, it was shocking to discover that bat breakage rates were not officially tracked by the MLB until the middle of the 2008 season. This was in response to the increased Multi Piece Failure (MPF) rates of maple bats witnessed that season. On April 15, 2008, Pittsburg Pirates hitting coach Don Long was struck on the left side of the face by shard of maple bat that had broken off. The shard sliced through his check muscle and severed the nerves in his face. Mr. Long never saw the projectile coming his way as his attention was directed toward the field. [16]. On April 25th of that same year, Susan Rhodes, a spectator of an MLB game was struck in the face and rendered unconscious by a fractured maple bat. Her injuries were extensive, as Ms. Rhodes was also struck on the left side of here face and had two jaw fractures, which required the implantation of four titanium screws. She may never fully recover. [17].

The main question was why all of a sudden were there more incidents involving maple bats MPF. Per the MLB's Safety and Health Committee findings, there was two primary causes for the multi-piece failure (MPF) of maple bats, 1) poor quality "slope of grain" and 2) ruptures caused by excessive bending [18]. Slope of Grain (SOG) is the term used by the wood industry to describe how straight the grain is along the edge (radial) and flat (tangential) faces of a wood billet. This describes how, as the straightness of the grain reduces the less durable the bat becomes. Their study also concluded that maple bats were three times more likely to break into multiple pieces over ash bats and four times more likely to break due to poor-quality slope of grain than an ash bat with similar failing.

This led the MLB to issue nine recommendations [18] to reduce the quantity of multi-piece bat failures (MPF) for the 2009 season. The implementation of these regulations did help reduce the MPFs of maple bats by 30 percent in 2009 [19] but, as the goal is to not have any MPF's, more independent research has been performed. Eric Ruggiero et al. [19] performed a series of durability tests per the new MLB requirements to introduce a new species of wood to be proposed as a new bat option. They first performed tests with the hallmark white ash bat and then compared the results of the suggested yellow birch species. Their findings suggest that birch is similar in durability, performance and material properties to white ash and therefore, suitable for bat production and use.

The key thing to understand regarding wooden bats is that density matters, as pointed out in Eric Ruggiero et al. [19] findings. Another key element is the so-called "sweet spot". This is the part of the bat barrel that when it strikes the ball in the right way the player can send the ball the farthest. For their study, they determined the bats BBCOR (Batted Ball Coefficient of Restitution) for each wooden bat tested. The BBCOR is a performance standard placed on all metal bats to ensure they have a wooden bat performance. The BBCOR and other performance standards will be explained further in chapter three. Once they had achieved the BBCOR's for their test subject, it was clearly evident that a high-density wooden bat would out perform a low-density wooden bat. Their data is summarized in Table 2.3 below.

Table 2.3 Comparison of BBCOR for Wooden Bats [19]

Location [in] (cm)	BBCOR HD Ash	LD Ash	HD YB	LD YB
3.5 (8.9)	0.403	-	0.409	-
4.5 (11.4)	0.450	0.449	0.442	0.451
5.5 (14.0)	0.470	0.474	0.471	0.471
6.0 (15.2)	0.476	0.479	0.477	0.477
6.5 (16.5)	0.481	0.480	0.481	0.477*
7.0 (17.8)	0.478	0.476	0.476	0.473
7.5 (19.1)	0.468	-	-	-
8.5 (21.6)	0.435	0.428	0.452	0.435
9.5 (24.1)	0.401	-	-	-

* Sweet spot determined to be at 6.5-in. (16.5-cm) location during isolation

Table 2.3 shows that the sweet spots of all high and low-density ash and yellow birch bats were at the 6.5 in location. It also shows that the high-density bats tend to outperform the low-density bats at locations near the sweet spot, while at locations farther away, the differences are more significant. [19]

But are yellow birch bats safer? Per the Eric Ruggiero et al. [19] series of testing, the results would suggest yes. They determined that the majority of yellow birch bats tested did not experience any Single Piece Failures (SPF) or Multi-Piece Failures (MPF) at the prescribed impact locations at velocities below the calculated threshold velocities. SPF/MPF were only seen to occur at velocities greater than the threshold velocities, thus further exhibiting that yellow birch is a suitable safer wooden bat for use in MLB play. Their data has been summarized in Table 2.4. Testing at the 14-inch impact location included more bats due to the fact that impacts at this location cause greater MPFs with larger free flying bat fragments.

Table 2.4 Durability Threshold Velocities Ash Bats with Yellow Birch Durability Relative to SPF and MPF Threshold of the Ash Bats

Location from tip of barrel [in (cm)]	**Velocity [mph (km/h)] Ash**		**Low-Density Yellow Birch**		**Med-Density Yellow Birch**		**High-Density Yellow Birch**	
	SPF Threshold	**MPF Threshold**	**SPF**	**MPF**	**SPF**	**MPF**	**SPF**	**MPF**
2 (5.08)	125 (201)	170 (274)	0/3	1/3	0/3	0/3	0/3	0/3
10 (25.40)	135 (217)	160 (258)	0/3	0/3	0/3	0/3	0/3	0/3
14 (35.56)	110 (177)	130 (209)	0/6	0/6	0/6	0/6	0/6	0/6
16 (40.64)	105 (170)	135 (217)	0/3	1/3	0/3	0/3	0/3	2/3

CHAPTER 3

INDUSTRY STANDARD TESTING METHODS

Chapter 2 reviewed several safety studies on both wooden and metal baseball bats, all of which employed various required testing methods. In this chapter, an exploration into each of these methods and others that go into determining baseball bat safety will be presented. Please note that all testing methods are compared to results based on white ash baseball bats, as they are still considered to this day as the gold standard bat for MLB play.

3.1 Ball Exit Velocity (BEV)

When the need arose to be able to quantify metal bats versus wooden bats, the first factor considered was the ball exit velocity (BEV). This is the velocity at which the ball leaves the bat. But in truth, since no one really cares about the direction of the ball (as long as it's fair), what is truly measured is the Ball Exit Speed (BES) or the Batted Ball Speed (BBS).

Players are continually trying to improve their BBS. A better BBS means that a player is getting the most desired result of the bat ball collision. Many factors go into the calculation of the BBS such as; bat speed (the speed the bat is traveling at contact), pitch speed (presumably at the home plate/strike zone), impact point on the bat ("sweet spot"), bat composition (based on BESR rating-discussed later in this chapter), and ball composition (Coefficient of Restitution (COR) rating). The equation for calculating the BBS is given by the following expression:

$$BBS = (q)*(\text{pitch speed}) + (1+q)*(\text{bat speed}) \quad (3.1)$$

where q is defined as collision efficiency. Collision efficiency is related to both the ball and bats coefficients of restitution (COR). This combination of COR values are known as the ball-bat coefficient of restitution or simply BBCOR. The range of these values typically obtained is 0.2 to 0.25.

3.2 Coefficient of Restitution (COR)

The Coefficient of Restitution (COR) is a metric used in physics to describe the elasticity of two colliding bodies. It is the ratio of their final relative speed to their initial relative speed. In baseball, it is used to quantify the "bounciness" of the ball and of the bat. The NCAA has put a limit on the performance of non-wooden bats based on their COR rating. The COR is given by Equation 3.2 and its range is between zero and one. A COR value of one shows the collision to be completely elastic and for values less than one the collision is inelastic.

$$COR\ (e) = \frac{Vf_{bat} - Vf_{pitch}}{Vi_{bat} - Vi_{pitch}} \quad (3.2)$$

Where:

Vf_{bat} is the final speed of the bat

Vi_{bat} is the initial speed of the bat

$Vf_{pitch\ is}$ the final speed of the ball

$Vi_{pitch\ is}$ the initial speed of the ball

The COR speaks directly to the amount an object may compress. When comparing metal to wood for a baseball bat, it is know that the metal bats will compress and then bounce back all or mostly all of the energy to the ball where a wooden bat will not. If a wooden bat compresses, it breaks. Therefore metal bats have an advantage, as they can be designed to give optimal "bounce" to a player, but in doing so, it also endangers the defending teams players.

3.3 Ball Exit Speed Ratio (BESR)

The NCAA, to further increase the safety of youth players, introduced the BESR in 2005. It supersedes the BEV/BES as measure of safety although the BES is still used when speaking to the exit speed of the ball after collision with the bat. The BESR is also a number that once it is known can be used to calculate the BEV/BES as shown in Equation 3.3. In its simplistic terms, the BESR is the ratio of the speed of the ball exiting from collision with the bat (BEV/BES) to the combined speed of the bat speed and speed of the pitch (at the plate), as illustrated in Equation 3.4. The purpose of the BESR is to quantify the "liveliness" of a non-wooden bat and account for the so-called "trampoline" effect that bats of metal or composite have been shown to have [20]. A simple example of the bat-ball collision is illustrated in Figure 3.1.

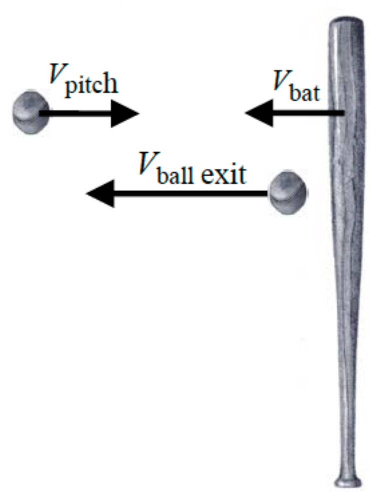

Figure 3.1 The ball-bat collision. [20]

Where:

V_{pitch} is the speed of the pitched ball just before collision with the bat

V_{bat} is the speed of the bat just before it collides with the ball (bat speed at the point of impact).

$V_{ball\ exit}$ is the exit speed of the ball just after it leaves the bat.

$$V_{ball\ exit} = (BESR+.5)\ V_{bat} + (BESR-.5)\ V_{pitch} \tag{3.3}$$

$$BESR = \frac{V_{ball\ exit} + .5(V_{pitch} - V_{bat})}{V_{pitch} - V_{bat}} \tag{3.4}$$

When $V_{pitch} = V_{bat}$ Equation 3.4 becomes

$$BESR = \frac{V_{ball\ exit}}{V_{pitch} -+ V_{bat}}$$

The BESR also takes into account the properties of the baseball. No two baseballs lots will perform alike, so when testing the non-wooden bats, a lot of balls are tested as well. This same lot is used for testing both the non-wooden and wood standard baseball bats so that a true BESR rating can be found.

Since the BESR rating depends on both the ball and bat material properties, additional information is needed in order to calculate its value. When testing a bat-ball pair, the setup is designed to maximize the "sweet spot" impacts. Installing the bat into a batting machine at a set pivot point does this. The moment of inertial about the bat pivot point, COR for the bat-ball collision, mass of the ball and the distance from pivot point to impact point is also needed. Having these values we can calculate the BESR rating for the bat-ball collision, which is given by equation 3.5 [20].

$$\text{BESR} = \frac{e + \frac{1}{2}\left(1 - \frac{mr^2}{I_p}\right)}{1 + \frac{mr^2}{I_p}} \tag{3.5}$$

Where:

e = coefficient of restitution of the ball-bat collision.

m = mass of the ball

r = the distance from the pivot point to where the ball hits the bat (see Figure 3.2).

I_p = moment of inertia of the bat about the pivot point. Note: this parameter depends on the mass of the bat as well as how the mass is distributed relative to the pivot point. The more mass distributed relative to the pivot point, the larger the moment of inertia.

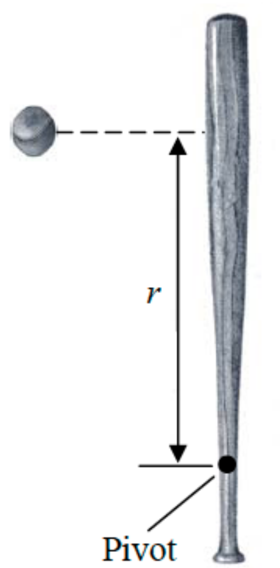

Figure 3.2 Illustration of the distance r from the pivot point to where the ball collides with the bat. [20]

The NCAA in conjunction with The Baseball Research Center (BRC) in Lowell Massachusetts, has developed a specific performance testing procedure to certify non-wooden baseball bats. Bats submitted of various lengths must first meet a minimum allowable moment of inertia given by the NCAA guidelines [21]. In essence, a ball cannon fires baseballs directly at a bat, which is secured in a bat pivot support. The balls when fired pass through a ball speed gate, which contains a series of sensors that detect the inbound and rebound speed of the ball. From the collected sensor information and other know factors the BESR is calculated by the lab as given in Equation 3.6.

$$\mathrm{BESR} = \frac{V_{\mathrm{R}} - \delta v}{V_{\mathrm{I}} + \delta v} + 0.5 + <\varepsilon> \tag{3.6}$$

$$\delta v = 136\ \mathrm{mph} - V_{\mathrm{Contact}} \tag{3.7}$$

where,

V_R = ball rebound speed sensor measurement

V_I = ball inbound speed sensor measurement

ε = correction factor

3.4 Ball-Bat Coefficient of Restitution (BBCOR)

After the BESR was introduced in 2005, studies were further conducted that focused on the comparison of performance of metal to wooden bats. In addition, to this, injury rates sustained by each bat type were also monitored. Over the course of a three-year study, Mueller and Marshall (2007) [22] determined that the BESR was not a significant rating factor in reducing player injuries from metal bats. This and other reports drove the

NCAA to create and implement a new rating called the Ball-Bat Coefficient of Restitution (BBCOR).

As the name suggests, it is derived from the Coefficients of Restitutions found for the ball and the bat together. As stated earlier, the COR is a measure of "bounciness" between two object in collision. Each object, in this case a bat and a ball, have their own individual COR ratings. The combined rating, BBCOR is a measure of the "bounciness" for the system of ball-bat collision.

The NCAA testing procedure for determining the BBCOR is similar to that of the BESR with the exception being 1) how the velocities are used in the calculation and 2) the Accelerated Break-In Protocol (ABI) [23] is used. The ABI is a method employed when testing metal and composite bats to simulate the repetitive uses most bat experience. It is a known fact that metal and composite bats yield a better performance after they are used or "broken-in". In order to keep the BBCOR in line with this fact the bats are broken-in and then tested. The BBCOR can then be represented as equation 3.8 [24].

$$BBCOR = \frac{v_R}{v_I}(1+r) + r + C_{ball} \tag{3.8}$$

where,

$$r = m\left[\frac{1}{W} + \frac{(L - BP - z)^2}{I - W(BP - 6)^2}\right] \tag{3.9}$$

$$e = \frac{v_R}{v_I}(1+r) + r \tag{3.10}$$

$$C_{ball} = 0.528 - e \tag{3.11}$$

m = mass of the ball (in ounces)

v_I = ball inbound speed

v_R = ball rebound speed

z = impact location measured in inches from the barrel

L = bat length

W = weight of the bat

BP = balance point relative to the knob of the bat

I = weight moment of inertia relative to pivot location

CHAPTER 4

MATERIAL PROPERTIES AND SAFETY

4.1 The Trampoline Effect

The bat-ball collision as is described by the Coefficient of Restitution (COR) or the "bounciness" of the system, is also describing the energy loss from that collision. In baseball, the more energy the ball has the farther it will travel. Therefore, when a ball collides with a bat they compress each other and some of the energy that was stored in the ball is now used to compress the bat. The degree to which the bat is able to return that energy to the ball is known as the Trampoline Effect.

A wood bat, due to its inherent material properties, does not compress to the same degree aluminum or any other composite baseball bat does. In the ball-wood bat collision, the baseball compresses to nearly one half its original size (see Figure 4.1). The result of this collision is that the ball loses about 75% of its internal energy in the compression and some energy is dispersed to the bats vibrational modes. But, in aluminum or composite bats, this is not the case.

When it comes to aluminum or composite bats, they can be designed to generate a bigger trampoline effect. Due to the nature of their construction, hollow bats have the ability to deform upon collision with the ball (see Figure 4.2). Therefore, the ball does not deform as much as with wood and retains its internal energy. In addition to this, the hollow wall of the bat can spring back quickly and return some of the stored energy to the ball increasing its exit speed from the bat. It is important to note that this return of energy happens while the bat and ball are still in contact, thus, analogizing the collision to that of a trampoline effect. Whereas in a wood bat-ball collision, the ball has already left the bat and reversed its direction by the time the bat recovers from what little deformation it has experienced. .

Figure 4.1 Image of a ball colliding with a wood baseball bat. [25]

Figure 4.2 Image of a ball colliding with a composite baseball bat. [26]

In reality, what is being experienced by the collision of theses two bodies comes down to what they are each composed of. The baseball is highly regulated as to size and material allowed but not the quality of those constitutes pieces. Per MLB rule 1.09 "*The ball shall be a sphere formed by yarn wound around a small core of cork, rubber or similar material, covered with two strips of white horsehide or cowhide, tightly stitched together. It shall weigh not less than five nor more than 51/4 ounces avoirdupois and measure not less than nine nor more than 91/4 inches in circumference* [3]." As these are all natural materials their performance properties will vary with temperature, use, and supply lot. Figure 4.3 shows a cross sectional area of a NCAA regulation baseball.

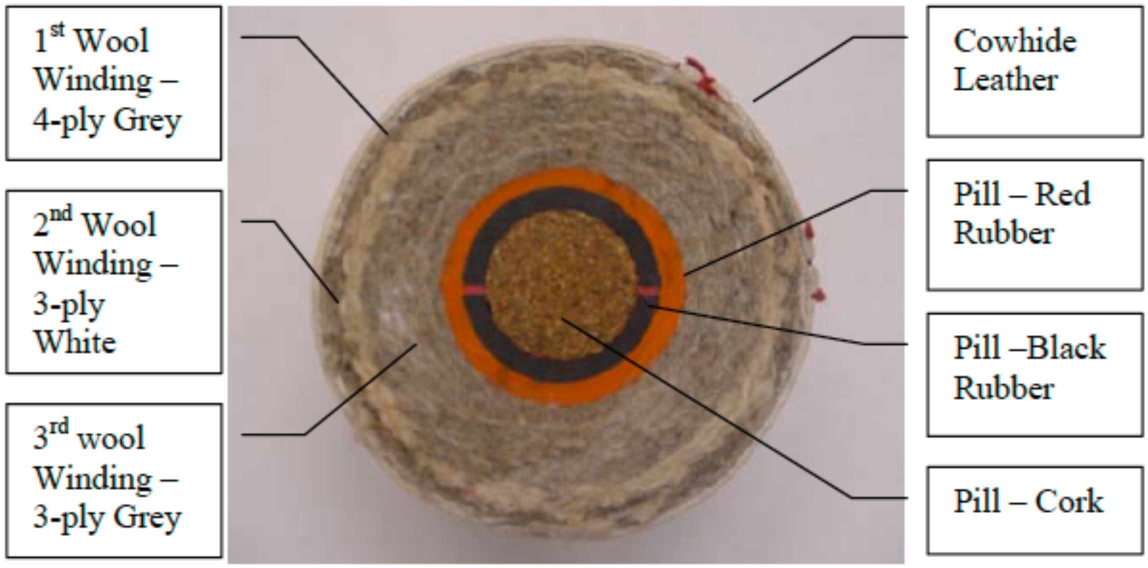

Figure 4.3 Cross-section of a NCAA baseball. [27]

To keep the performance of the ball controlled, the MLB and NCAA require the balls to have a COR rating of .5460 and .555, respectively. Having the standard helps to keep play fair but as the ball is subject to environmental changes so will its performance change. A study by Drane and Sherwood [27] illustrated that a colder baseball at speeds akin to MLB play, exhibit more changes in their COR versus heated ones at the same test speed. Showing that, the colder the ball the slower the rebound speed, about 3% from the standard. Whereas the higher the temperature of the ball correlates to a COR change of less than 1%.

For baseball bats, the variety is large. There are several species of wood and many other varieties of metal or composite. Recent studies and discussion have illustrated that one of the main factors in bat performance and safety is the types of vibrational frequency each bat experiences. There are two types of vibrational modes, bending and hoop. The material that can generate a “hoop” mode or frequency is the only material that experiences the trampoline effect. These are in essence the vibrational frequencies created through the design and properties of the material. Wooden bats only experience bending modes.

Bending modes describe the flexibility of the bat along its longitudinal axis in terms of frequency. The "sweet spot" or "sweet zone" of a baseball bat is typically found between two nodes on the bat barrel. The reason this area is so sweet is because it is the only area on the bat where the frequency of the impact negligibly excites these nodes [28]. This results in less energy transferred from the ball to the bat, thus, yielding a greater BEV.

However, a hollow bat of metal or composite has both bending and hoop modes. The addition of the hoop mode is due to the hollow shell shape these bats tend to have. Hoop modes involve only the radial oscillation of the bat barrel [28] and have the ability to store the impact energy from the ball-bat collision and then return that energy to the ball prior to it leaving the bat. The hollow barrel wall compresses instead of the ball so it behaves like a spring. This in turn gives the ball more "pop" on exit sending at an increased velocity of that of a traditional wooden bat.

This spring like behavior has started a controversy over the performance of composite and metal bats. Bats of this nature can be tuned so that optimal hoop modes and bending mode nodes line up is such a way that players can reap the benefit of a higher BEV. As stated earlier, to try to keep their performance similar to that of wood, the NCAA and National Federation of State High School Associations (NFHS) have issued restriction on the BBCOR. The main goal of which is to stop injuries to players from lack of reaction time as a result from increased bat performance.

4.2 Slope of Grain

The material characteristics of wooden bats are both determinate of their performance as well as their failure. Mechanical properties such as toughness, Modulus of Elasticity, bending strength and Modulus of Rupture can determine if a wood species is a good choice for a baseball bat. But all of these factors are dependent on what is known as Slope of Grain (SOG).

Slope of grain is defined as how close to parallel a piece of wood is cut with respect to the longitudinal axis of the wood cells in the tree [6]. This longitudinal axis can be thought of as the zero degree line of the log. The closer to parallel a piece of wood is cut to this line or grain the stronger the wood becomes. Subtle angular deviations have been shown to impact the strength capabilities of wood severely [6,29,30]. Wood will always split along its longitudinal or zero degree axis but, in modern lumbering industries most trees are cut with saws rather than split. This has been shown to be a concern [6], due to the fact that cuts made with saws may not be aligning properly to the longitudinal axis.

There are two types of slope of grain, radial or edge-grain face and tangential or flat-grain face. Radial SOG is the angle the annual rings make with the zero degree line as seen in Figure 4.4. Of the two types, radial is the easiest to visually resolve. Tangential SOG is the angle of the grain on the flat-grain face. It is the angle the wood fibers themselves make with the zero degree line of the wood. While it is easy to locate these fibers in the ash species, with the sugar maple species, it is more elusive. Figure 4.5 show the addition of an ink mark to help manufacturers locate the wood grain. In both Figure 4.4 and 4.5 the red line represents the zero degree axis or central line of the wood billet.

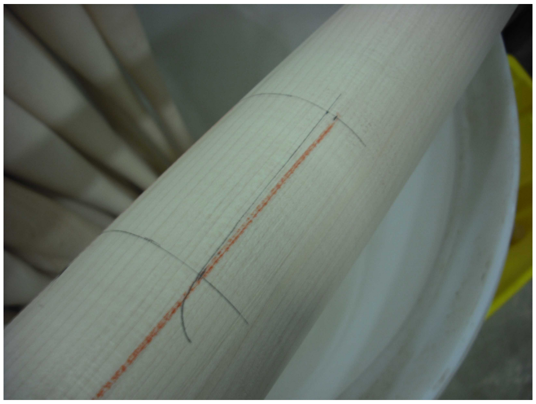

Figure 4.4 Radial SOG. [6]

Figure 4.5 Tangential SOG. [6]

SOG plays a significant role in baseball bat safety. It is a commonly know fact in the wood industry that wood strength depends on the SOG. Due to the complexity of having two types of SOG to be considered, a common practice to measure SOG is the "1 in X" rule. This rule tells how many units of length are traveled on the bat before you see a 1-unit of change perpendicular to the length of the tree [29]. As an example, if the SOG was 1:20, which would mean you were able to travel 20 units of length before, a 1-unit change is realized. But that change has contributed to loss of strength in the wood by approximately 7%. In essence, the higher the X value, the stronger the wood will be. Figure 4.7 demonstrates the relationship of the 1 in X rule in association with SOG. As a further example of just how important SOG is to wood strength, one need only turn to the Hankinson equation. Hankinson discovered that when the SOG is less than perfect the strength of the wood decreases rapidly [30]. Equation 4.1 below describes this relationship.

$$N = \frac{PQ}{P\sin^n\theta + Q\cos^n\theta} \tag{4.1}$$

where,

N = the strength at an angle Θ to the fiber direction

P = the strength perpendicular to the fiber

Q = the strength parallel to the fiber

n = an empirically determined constant

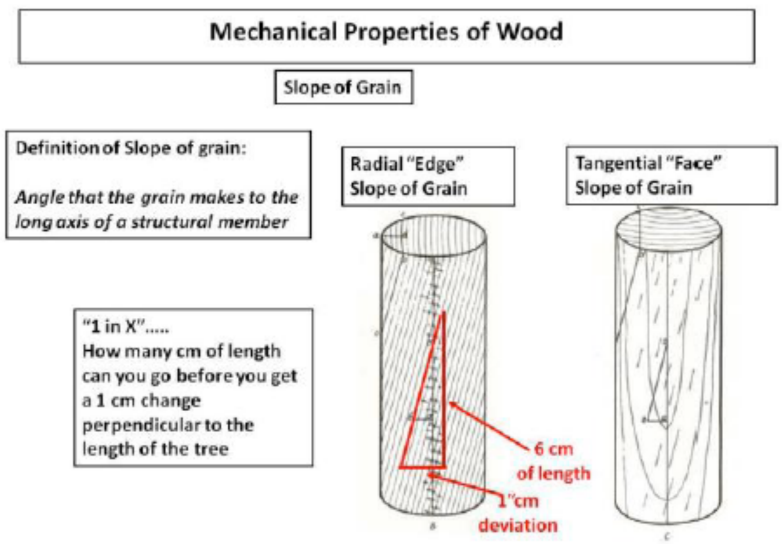

Figure 4.7 Illustration of SOG in wooden dowels. [29]

Derived from the Hankinson equation is a graph (see Figure 4.8) of average relationships between many wood species that illuminates the effect SOG has on wood properties. Per the Wood Handbook, rupture modulus falls close to the curve of Q/P = 0.1 and n = 1.5, impact bending is close to the Q/P = 0.05 and n = 1.5, and the Modulus of elasticity is close to the Q/P = 0.1 and n = 2 [30]. From this graph, it can clearly be seen that the cure with the deepest slope shows the best relationship of SOG, with regard to strength it is the one at Q/P = 0.05 and n = 1.5. Here, the bending strength of the wood is maximized relative to its SOG. Therefore, woods that exhibit this property are the better choice for baseball bats.

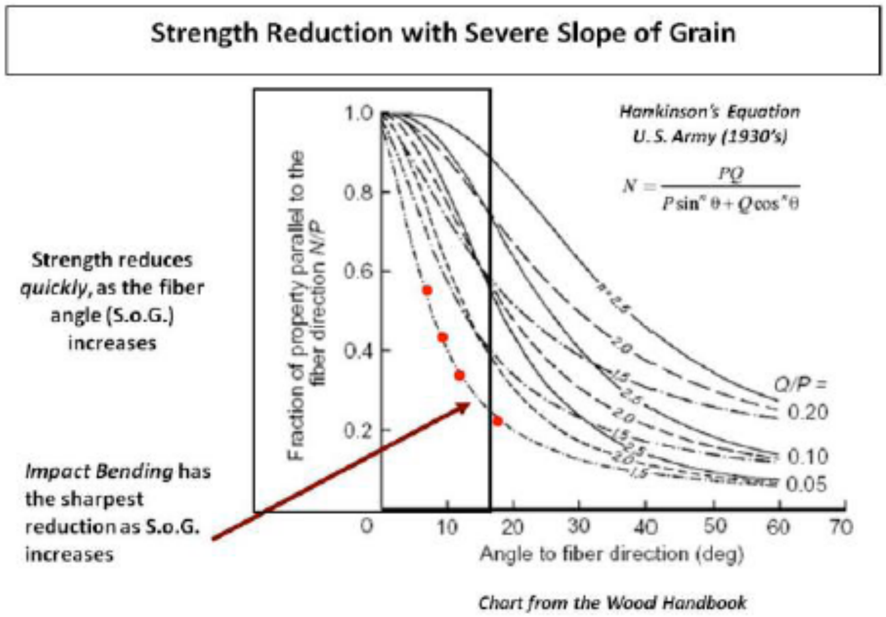

Figure 4.8 Graphical representation of Hankinson equation. [29]

The relationship of SOG to strength also determines the type of failure a species of wood will have. It is a fact, that bats break but if we can control the way they fail we can ensure player and spectator safety. The rash of maple bat MPFs experienced in the 2008 MLB season was largely attributed to 1) poor SOG and/or 2) ruptures caused by excessive bending.

The SOG failures experienced that season were found largely in Maple bats. It was discovered that due to their diffuse porous nature, manufacturers had trouble determining the tangential SOG and were sending out bats with as little as a 1:4 SOG. That equates to about a 14 degree SOG and strength of about 25% [30]. From their findings, it was determined by the MLB that all bats must have a SOG of 1:20 or greater. This will ensure strength of at least 90% and correlates to a 3% or under fiber angle (SOG). In creating bats with a 1:20 SOG, the type of failure will typically be that of a rupture.

Bats designed with a near perfect SOG will exhibit a rupture failure, which is considered to be a good failure as the bat stays in one piece. The failure occurs at the handle usually due to an inside pitch exceeding the strength of the wood. Failures due to poor SOG issues are MPFs and have an oval quality to the split. These are the most dangerous and dramatic types of failures. Figure 4.9 shows examples of a rupture failure and Figure 4.10 show a SOG failure.

Figure 4.9 Rupture failure. [6]

Figure 4.10 Failure due to poor SOG. [6]

4.3 Baseball Bat Design

Of all the factors to consider in constructing a safer baseball bat, its shape must be studied. The physical appearance of the baseball bat has evolved over the past century to the iconic look they have today as seen in Figure 4.11. But this evolution was not by accident; early players would test out different shapes and judge their "feel". The "feel" of a bat comes from its moment of inertia. (MOI)

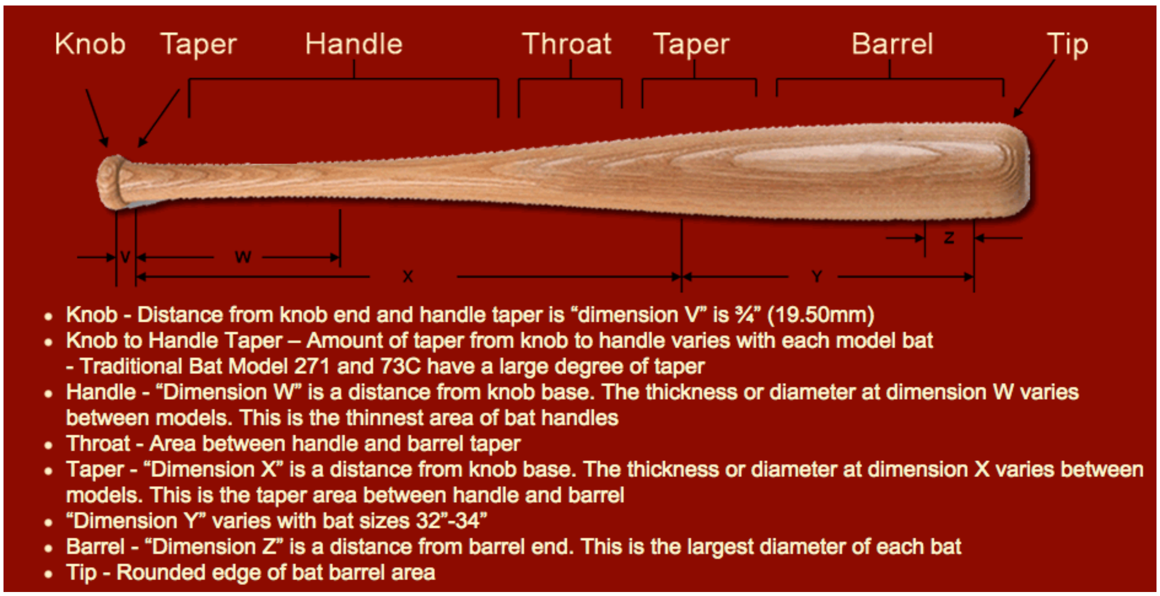

Figure 4.11 Modern day baseball bat [31]

The moment of inertia for any object describes that objects resistance to rotation. It's a relationship of an objects' weight distribution to its center of mass. However, two objects may share the same weight but if their shape is different they may have different moments of inertia. This is why some bats will feel heavier than others when swung. As a factor of safety, the NCAA has a minimum MOI requirement in place to reduce the swing speed of players. This is in the belief that a longer swing speed will give pitchers more time to react.

The MOI in baseball bats is severely affected by their shape. Some believe that the failures experienced by wooden bats can be contributed to shape. Bat manufacturers have maximized the barrel to generate a bigger “sweet spot” and higher MOI but in order to keep the weight requirement; they have minimized the neck of bats. With a thinner neck, the wooden bat cannot with stand an impact to the handle region as its predecessor in the first half of the 20th century had. It is a firmly held belief between fans and players that thinner necks equal more broken bats.

And with metal or composite bats, material concentrations can be varied with shape where needed and still meet weight and length requirements without losing strength. This in turn giving bats in this category a higher MOI over traditional wooden bats. Resulting in metal or composites having a more efficient collision with the ball. It also means they have a higher BEV.

The barrel design of the bat is also important to performance and safety. Although all leagues have a maximum diameter requirement they do not specify where the MOI can be located. Since wooden bats are solid, the bat weight is distributed through the body, creating a narrow neck and heavier barrel [13]. It has been proven [14] that the mass distribution has a quadratic effect on resistance to angular acceleration: the relative extra weight on the barrel of a wooden bat increases the torque needed to swing it, thus reducing swing speed and BEV. However, the barrel of a metal or composite does not suffer from this relationship. Bats of this type experience the trampoline effect, which adds to BEV ratings. Due to the safety concerns surrounding the barrel of metal or composite, the BBCOR rating of 0.50 has been implemented.

CHAPTER 5

DISCUSSION

5.1 Conclusions

A variety of studies that focused on material properties of baseball bats in regard to safety were reviewed. Based on this review, correlations can be drawn to show how material properties directly effect bat safety. For example, the ball exit velocities (BEV) are dramatically influenced by the trampoline effect exhibited in metal/composite bats. This causes significant and sometime life threatening injuries to youth players. Multi Piece failures (MPFs) from wooden bats are directly a result of poor slope of grain (SOG). A MPF can seriously injure several players and/or spectators with cuts and impalements.

Due to the recent rash of injuries attributed to baseball play; many researchers and bat manufacturers have been working together for solutions. Advancements have been made in understanding how these factors contribute to safety issues and implementations such as the BBCOR and SOG requirements have reduced injuries. But the problems still exist.

More research is needed in how to tune metal and composite bats in order to reduce the benefits of hoop frequencies. By limiting or eliminating the hoop frequency a metal or composite bat would only be subject to bending modes, as in a wooden bat. Whereas the safety concern associate with MPFs of wooden bats has been defined, the research shows that SOG is the main contributing factor to this type of failure.

5.2 Suggestions for Future Work

From an analysis of safety studies, many suggest that the actual design of wooden bat that has evolved may contribute to the injuries witnessed. While this most definitely plays a part in their failure, it is the SOG quality that will promote failure. However, that is not to say that improvements to wooden bat designs cannot aid in safety.

A study conducted by Ravindra et al. [32] showed that carefully placed grooves along the wooden bat could improve the bats' life expectancy and control crack propagation. Their idea was to break up the excessive vibrations created by the bat-ball collision [32] with these grooves. Another company, Radial Bat, had the idea to improve wooden bat safety by creating a tight grain pattern out of twelve carefully selected wood wedges. According to the creator, the bats are more difficult to break and if they do, it would not be due to a MPF [33]. Further investigation into this and other methods for controlling the forces exerted on a wooden bat warrant exploration.

Although wooden bats have been used in baseball for over a century, only recently has attention been paid to their failure rates. Continued tracking of wood species, type of failure, weight distribution of the failed bat, SOG and number of impacts can only help us to improve our understanding of the mechanism of wooden bat failure. Perhaps even regular ultrasonic testing of the bats to look for cracks or voids in the structure would improve failure rates.

Research continues in the field of composite, geared toward finding a combination of material that aligns in properties to wood. Attention should be focused on structure, density and impact strength. Perhaps a composite combination can be found that is solid but with an internal structure similar to wood. But until such a material is found, the understanding of aluminum alloy bats needs to continue to develop. As a bat material that has only been in use for the past forty years, we are still in its infancies as to its behavior.

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APPENDIX A

AVERAGE PITCHER REACTION TIME EQUATION

Appendix A shows the equation to calculate reaction time.

$$\frac{X\ miles}{hour} * \frac{1\ hour}{60\ minutes} * \frac{1\ minute}{60\ seconds} * \frac{5280\ feet}{1\ mile} = X\ \frac{feet}{second} \qquad \text{A.1}$$

Equation A.1 is used to find the speed of the ball directed to the pitcher from a distance X.

Use the result, X ft/sec from Equation A.1 to find the time a pitcher has to respond by solving for V in equation A.2

$$\frac{X\ feet}{seconds} * \frac{distance\ from\ pitcher}{V} = second\ to\ respond \qquad \text{A.2}$$

APPENDIX B

COLLEGIATE PITCHER AVERAGE REACTION TIMES

Table B.1 shows calculation for pitcher reaction time based on a 60’ distance from pitcher to hitter for both wood and metal bats based on cited studies.

Table B.1 Average Pitcher Reaction Time

	Wood Bat Reaction Times			Metal Bat Reaction Times		
Study	BEV Wood Bat mph	Distance Traveled by ball ft/sec	Average Reaction Time to Pitcher (ART) sec	BEV Metal Bat mph	Distance Traveled by ball ft/sec	Average Reaction Time to Pitcher (ART) sec
Bryant et al.	88.1000	129.2133	0.4643	91.9000	134.7867	0.4451
Greenwald et al.	97.9000	143.5867	0.4179	102.4000	150.1867	0.3995
Nicholls et al.	91.2000	133.7600	0.4486	98.4000	144.3200	0.4157
*based on collegiate field distance between the pitcher and batter as 60'						

APPENDIX C

LITTLE LEAGUE PITCHER AVERAGE REACTION TIMES

Table C.1 shows sample calculation based on Little League field distance between pitcher and batters as 44'

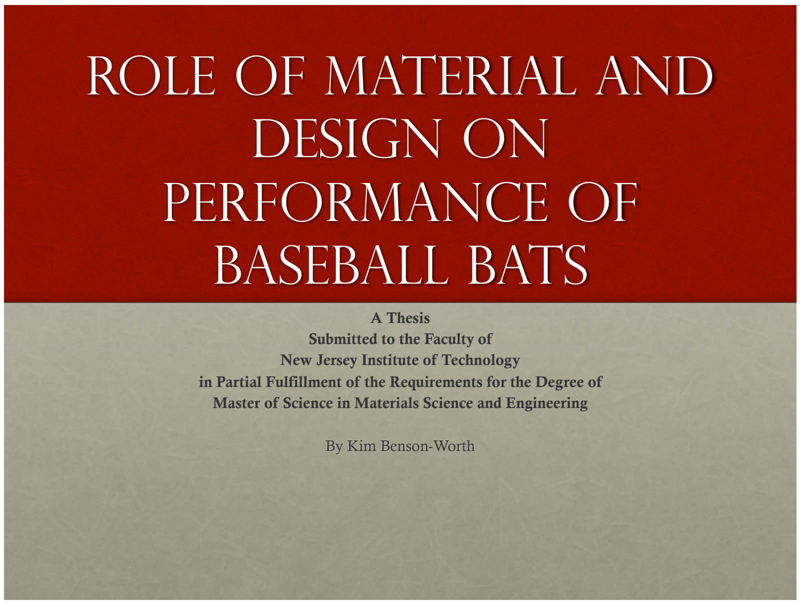
Table C.1 Average Pitcher Reaction Time

BEV Metal Bat mph	Distance Traveled by ball ft/sec	Average Reaction Time to Pitcher (ART) sec
40.0000	58.6667	0.7500
50.0000	73.3333	0.6000
60.0000	88.0000	0.5000

APPENDIX D

PRESENTATION SLIDES

Appendix D shows the presentation slides from Thesis defense.



Baseball Safety Statistics

- Baseball/Softball lead the pack in injuries requiring ER attention
- Of those injuries the majority are to the head or chest
- In years between 1973-95 Baseball/Softball had the highest recorded rate for sports fatalities for children between the ages of 5 and 14 with 88 deaths.
- Of those death 77% were due to a batted, pitched or thrown ball impacts to the chest verse the head

Baseball Safety Statistics

(The role of the bat)

- 75% of ball-related injuries (49% of all injuries) to Little League pitchers are due to impact from the batted ball.
- Risk of injury increase to pitchers when hitter use metal or composite bat
- From 1973-83, 35% of the 23 deaths among pitchers were attributed to chest impacts from batted balls
- Commotio cordis (death from blunt thoracic trauma in the absence of cardiac abnormality) accounts for 2-4 deaths in baseball per year.

BASEBALL SAFETY STATISTICS

(THE ROLE OF THE BAT)

- Major League pitchers have been hospitalized by line drives (Steve Woodard 2001 hit by Frank Thomas)
- Spectators have been seriously injured from broken baseball bats (Susan Rhodes 2008)

APPROACH

- Performed a review of multiple studies that focused on
  - injuries attributed to baseball bat performance
  - material properties of the baseball bats
  - baseball bat performance characterization

FINDINGS

Wood

- Single Piece Failure (SPF)
- Multi Piece Failure (MPF)

Metal/Composite

- Ball Exit Velocity
- Bat-Ball Coefficient of Restitution (BBCOR)
  - Trampoline effect
  - Hoop frequencies

WOOD BASEBALL BATS

Single Piece Failure

- SPF failures are due to the ball hitting the bat in a spot where the impact forces are greater than the strength of the bat at that location.
- This is known as a rupture.

Multi-Piece Failure

- MPF are when the bat completely breaks apart.
- This is known as a Slope of Grain failure.

METAL/COMPOSITE BATS

- Out perform wooden bats
  - higher Ball Exit Velocity
  - tunable Moment of Inertia
  - hoop frequencies
  - trampoline effect

CONCLUSIONS

- The material properties of the bat have a direct relationship to how safe it is
- BEV are dramatically influence by the trampoline effect in metal and composite bats
- Poor Slope of Grain (SOG) will typically produce MPFs in wooden bats

SUGGESTIONS

- To reduce the effects of chest impacts to youths organization should introduce chest protectors
- More research into limiting the effects of hoop frequencies and the trampoline effect
- Manufacture wooden bats by splitting the billet not sawing them
- Perform periodic Ultrasonic testing of wooden bats to check for hidden imperfections

SUGGESTIONS

- Create new wood designed bats to limit the vibration propagation
- Develop a composite that behave as a wooden bat does

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