JOURNAL OF APPLIED BIOMECHANICS, 2005, **21**, 18-30

Modeling Deformation Behavior of the Baseball

Rochelle Llewelyn Nicholls[1,2], Karol Miller[1], and Bruce C. Elliott[2]
The University of Western Australia

Regulating ball response to impact is one way to control ball exit velocity in baseball. This is necessary to reduce injuries to defensive players and maintain the balance between offense and defense in the game. This paper presents a model for baseball velocity-dependent behavior. Force-displacement data were obtained using quasi-static compression tests to 50% of ball diameter (n = 70 baseballs). The force-displacement curves for a very stiff baseball (Model B) and a softer type (Model C) were characterized by a Mooney-Rivlin model using implicit finite element analysis (ANSYS software, version 6.1). Agreement between experimental and numerical results was excellent for both Model B ($C_{10} = 0$, $C_{01} = 3.7e^6$ Pa) and Model C ($C_{10} = 0$, $C_{01} = 2.6e^6$ Pa). However, this material model was not available in the ANSYS/LSDYNA explicit dynamic software (version 6.1) used to quantify the transient behavior of the ball. Therefore the modeling process was begun again using a linear viscoelastic material. G_∞, the long-term shear modulus of the material, was determined by the same implicit FEA procedure. Explicit FEA was used to quantify the time-dependent response of each ball in terms of instantaneous shear modulus (G_0) and a decay term (β). The results were evaluated with respect to published experimental data for the ball coefficient of restitution at five velocities (13.4–40.2 ms^{-1}) and were in agreement with the experimental values. The model forms the basis for future research on baseball response to impact with the bat.

Key Words: hyper-viscoelastic behavior, finite element method

Regulating baseball response to impact is a potential method for controlling the velocity of balls hit into the infield in baseball. This is necessary in order to reduce catastrophic impact injuries to baseball pitchers, which accounted for 35% of baseball related fatalities in children between 1973 and 1985 (Viano, Andrzejak, & King, 1992). The imbalance between offensive and defensive performance in college baseball has also been partly attributed to balls that are too “lively” (*NCAA News*, June 12, 1999). However, the focus of attention has remained largely on the use of high-performance baseball bats (e.g., Greenwald, Penna, & Crisco, 2001).

[1] School of Mechanical Engineering, and [2] School of Human Movement and Exercise Science, The University of Western Australia, Crawley, Perth, WA 6907, Australia.

Less consideration has been given to the contribution of the baseball to the dynamics of bat-ball impact, despite recommendations such as those of Heald (1999), who suggested increasing ball "compressibility" as a method of controlling ball exit velocity (BEV). For such a recommendation to be instituted, the deformation response of the baseball during high-speed impact must be quantified.

Baseballs are constructed in four layers, consisting of a cork or rubber core wound in grey and white wools encased in two stitched pieces of leather. Regulation baseballs have a diameter of approximately 7.2 cm and mass of about 145 g. The sole performance indicator used to establish regulations on baseballs is coefficient of restitution (COR), which is determined by firing the baseballs at 26.6 ms^{-1} against a flat wall, and reported as the ratio of outbound to inbound velocity. Baseballs are currently required to have COR less than 0.555 (*NCAA news release*, Sept. 27, 1999). However, COR measurements provide no indication of the process of energy loss during the impact, and the results have been shown to be specific to the ball model and pre-impact velocity of the ball (Hendee, Greenwald, & Crisco, 1998).

No experimental studies have been conducted on the material response of the baseball in the strain range representative of bat-ball impact. Adair (1997) speculated that during such an impact the baseball might be compressed to 50% of its original diameter. However, previous research is limited to uniaxial compression tests up to 10% of ball diameter, from which simple estimates of stiffness were made from the gradient of the load-displacement curve (Crisco, Hendee, & Greenwald, 1997; Hendee et al., 1998). Chauvin and Carlson (1997) used pressure-sensitive film to measure deformation area during COR tests. Such film requires contact of up to 5 s to obtain precise measurements and thus cannot give a complete representation of ball compression. There have been no other experimental measurements of baseball deformation during either COR tests or bat-ball impact.

Numerical methods such as finite element analysis (FEA) are very valuable in providing mathematical description of the large-deformation behavior of elastomeric materials such as those used in baseball construction. Mustone and Sherwood (1998) developed a model for baseball behavior based on the Mooney-Rivlin rubber-like formulation. Ball COR of 0.710 was reported. However, details of the quasi-static and impact experiments used to obtain this result were not given. Smith, Shenoy, and Axtell (2000) adopted a linear viscoelastic model to quantify the velocity-dependent nature of baseball behavior and obtained COR of 0.600, decreasing to 0.450 at higher test speeds. Neither study gave any description of the ball behavior during the impact period, or the effect of modifying ball properties on dynamic behavior. The purpose of the present research was to develop a constitutive model to describe baseball behavior during impact for a very stiff and a softer type of baseball typical of those used by high-performance players.

Methods

To obtain force-displacement data, we conducted uniaxial compression testing of 70 baseballs from 7 models currently used in college and professional baseball, using the Instron 8501 materials testing machine (Instron Corp., Canton, MA). Each ball was positioned between two circular stainless steel platens. The upper platen was attached to a calibrated 100-kN load cell (resolution = 0.0001 N). Testing was conducted at 1 mm·s^{-1}, as pilot testing at 1, 0.1, and 0.01 mm·s^{-1} produced no remarkable differences in the force-displacement curves. The onset of the loading phase was indicated by the first nonzero force reading, and terminated at 35.8 mm (50% of undeformed baseball diameter). Only one loading cycle was completed for each ball due to the destructive nature of the test. Force-displacement data were sampled at 5 Hz and normalized to 100 data points, as a percentage of maximum displacement.

The surface of the baseball is irregular due to its pattern of raised seams. Testing for the effect of ball orientation on the force-displacement relationship was undertaken using two orientations: one in which the contact points for the upper and lower platens were on the ball cover, and the other in which the ball was orientated on its seams (Figure 1).

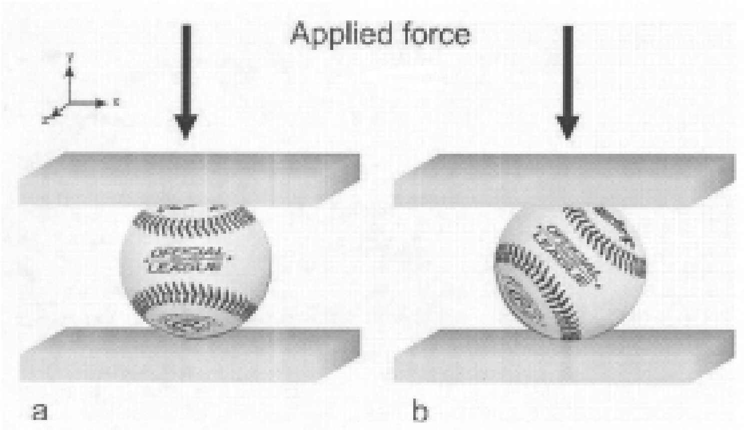


Figure 1 — The effect of ball orientation on force-displacement relationships was quantified using two orientations: (a) one in which force was applied on the ball cover (at the widest point in the xy, xz, and yz planes), and (b) one in which the ball was orientated on its seams.

Implicit FEA was used to provide numerical description of the hyperelastic behavior. ANSYS 6.1 software was used to replicate the experimental setup (Figure 2). The ball was modeled as a solid sphere (radius 36 mm), subdivided to a 1/8th section due to the symmetry of the structure. The ball was meshed with 500 eight-noded hexahedral elements. The adequacy of the mesh was assessed by repeating the analysis using meshes of 108 and 2,048 elements, with less than 1% difference in force evident at 20 data points along the force-displacement curves. Being much stiffer than the ball, the steel platen was modeled as a rigid body to reduce computational cost.

Description of material behavior in elastomers is commonly undertaken using hyperelastic theory, in which the existence of a stored strain energy function, W, is assumed (Ogden, 1984). In this case the well-known Mooney-Rivlin hyperelastic strain energy function (Mooney, 1940) was adopted:

$$W = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) \quad (1)$$

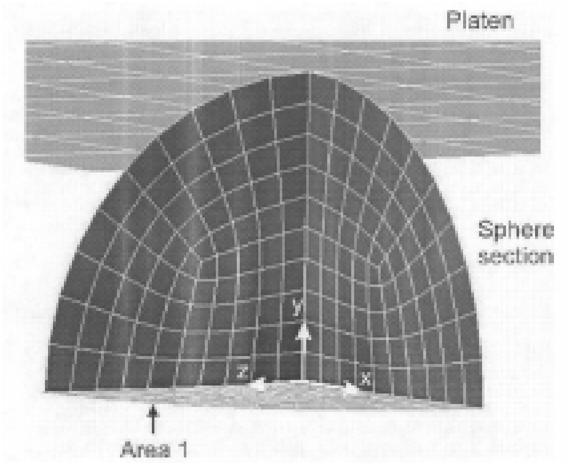


Figure 2 — Model of a 1/8th section of a baseball, showing FE mesh and 8-node hexahedral element with coordinate axes. The steel platen is meshed with ANSYS contact elements. Shown is Area 1, from which reaction forces are computed to determine the response of the ball to compression.

The assumption of isotropic material response allows the scalar *W* to be expressed in terms of strain invariants (Ogden, 1984). The assumption of isotropy is reasonable as the ball may have an angular velocity exceeding 2,000 rpm at impact with the bat (Adair, 1997), and hence its orientation during impact is entirely random and any effects attributable to the asymmetric structure of the ball will also occur randomly. As a result, strain energy *W* depends on the histories of strain invariants only. The strain invariants *I* are given by:

$\bar{I}_1 = Trace[B]$, where [B] is a left Cauchy-Green strain tensor;

$$\bar{I}_2 = \frac{\bar{I}_1 - Trace[B]^2}{2I_3}$$

$$\bar{I}_3 = det[B]$$

The application of the Mooney-Rivlin model required estimation of the constants C_{01} and C_{10} to fit the experimental force-displacement data. Two separate cases were considered. Of the 7 baseball types tested, Model B (in cover orientation) exhibited the steepest force-displacement curve and was assumed to produce the highest COR. A set of material constants was also devised for Model C (in seam orientation), which had the flattest force-displacement curve and was deemed to represent the softest model (Figure 3). Systematic variation in the values of C_{10} and C_{01} was undertaken so as to provide the best fit to the force-displacement data.

Contact between the ball and platen was defined using the robust general surface-to-surface contact algorithm with a friction coefficient of 0.2. Symmetry constraints were imposed on all exposed internal surfaces of the ball, and the platen constrained for motion in the vertical (-y) direction only. Loading was applied to

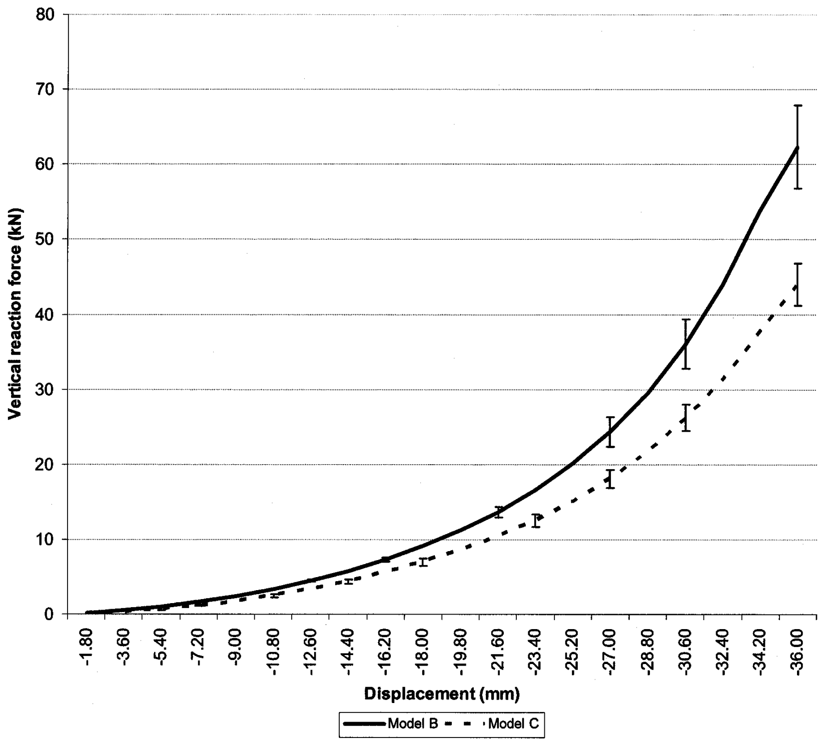


Figure 3 — Force-displacement data for the extremes of baseball behavior. Data from Model B is given as a solid line, that from Model C as a dashed line. Error bars are shown to indicate intramodel variation.

the ball via the nodes of the platen in the vertical (-y) direction, at 1 mm·s^{-1}. The load was applied in 20 time-steps and terminated at 50% of the section height (18 mm). The resulting nonlinear problem was solved using the Newton-Raphson method. Vertical reaction force data (F_Y) for the nodes of Area 1 (shown in Figure 2) was acquired using the post-processing functions of ANSYS. These data were multiplied by 4 to account for the symmetry of the model, and plotted against experimental force-displacement curves to evaluate the material parameters.

In our view, the most efficient and effective approach to modeling is to approximate a solution with the simplest available model, only progressing to more complex models should the simpler model not adequately characterize the material behavior. Hence our choice of the Mooney-Rivlin model (with 2 material constants) to describe the force-displacement response. This model provided an excellent description of the force-displacement (static) response—but in order to fully quantify the material behavior, the veracity of this model in a dynamic situation had to be established. The Mooney-Rivlin material model was not available in our explicit FE package (ANSYS/LSDYNA, version 6.1; LSTC, Livermore, CA). Thus we were forced to restart the modeling process with a different material model. Our choice was the well-known linear viscoelastic model, which is also useful for describing time-dependent behavior but requires 3 constants to describe the material behavior:

$$G(t) = G_\infty + (G_0 - G_\infty)e^{-\beta t} \quad (2)$$

Implicit FEA of the baseball compression experiments was repeated using this material model to determine G_∞. An initial estimate of the value of G_∞ was made using the assumption for Mooney-Rivlin behavior that, during infinitesimal strain conditions, the shear modulus is equal to twice the sum of constants C_{10} and C_{01} (Ogden, 1984). However, due to the large deformation experienced by the ball, this value was subsequently adjusted to provide best fit to the experimental force-displacement results.

The value of G_0 was quantified using explicit FEA (ANSYS/LS-DYNA 6.1). For this analysis the decay constant β was set close to 1 ms, which is the typical duration of bat-ball impact (Adair, 1997). The representation of β as equating to the contact duration has been shown by Miller (2000) as appropriate for linear viscoelasticity. In the analysis, a homogeneous solid sphere meshed with 2,000 eight-node hexahedral explicit elements was impacted on a "wall" represented by a single vertical rigid element (Figure 4), and the COR quantified 0.005 s post-impact. The adequacy of the mesh was assessed by repeating the analysis with meshes of 432 and 8,192 elements, with less than 1% variation in COR being apparent. Horizontal velocity (v_x) of 26.6 ms^{-1} was initially applied to the ball, as

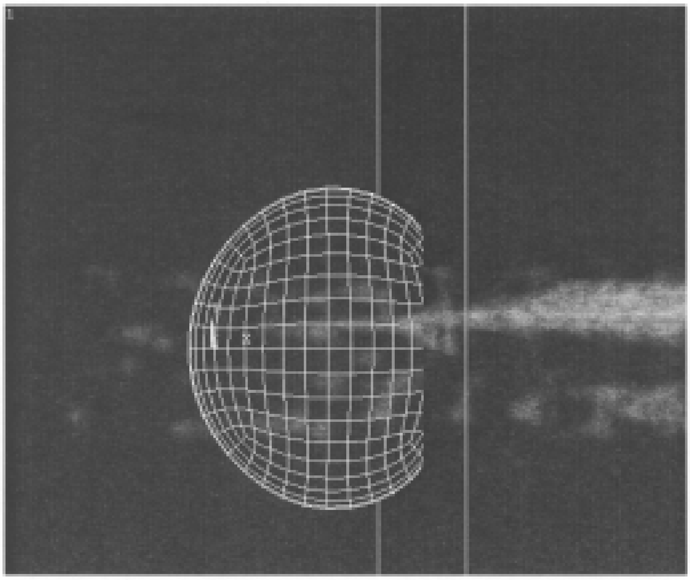


Figure 4 — Geometry for explicit analysis of baseball transient behavior. The baseball is represented by a solid sphere of 8-node hexahedral elements, the wall by a stationary single vertical shell element. In this figure, deformed geometry at the instant of maximum compression is shown for Model B.

this is the velocity at which all professional baseball models are tested for adherence to COR standards. The appropriateness of the model was verified through tests at 13.4, 20.1, 33.5, and 40.2 ms^{-1}. G_∞ and β were held constant and the value of G_0 was adjusted to provide solutions comparable to the experimental COR data of Hendee et al. (1998).

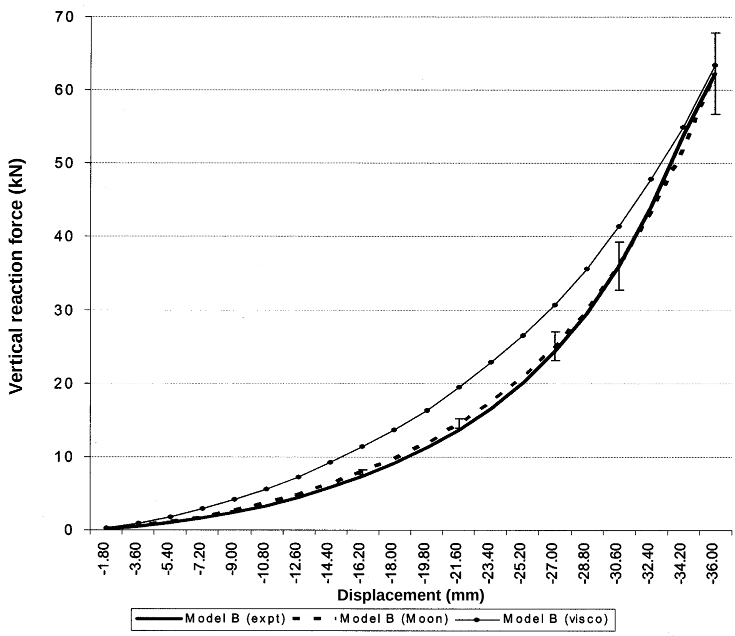
Results

The nonlinearity of the experimental force-displacement curves for compression to 50% of ball diameter is evident in Figure 3. Uniaxial compression tests with the baseball positioned in cover orientation produced consistently steeper force-displacement curves and greater peak force than in seam orientation, for all models. To assess the repeatability of measurements, the coefficient of variation (standard deviation divided by the mean) was calculated for normalized force-displacement curves of four randomly selected balls in each model. The values ranged between 0.05 and 0.11 for models when tested on the cover, and 0.04–0.12 for seam orientation. No published data are available for comparison. The variation was attributed to slight aberrations in ball positioning. The data from ball models chosen for further analysis (Model B and Model C) are illustrated in Figure 3, indicating wide variation in force-displacement response between two models currently used in high-performance baseball.

Comparison of the Mooney-Rivlin and linear viscoelastic models in characterization of the force-displacement curves is given in Figure 5a and 5b. While the linear viscoelastic model tended to overestimate the relaxation behavior, excellent agreement was obtained using the Mooney model for both types of baseball. Systematic variation in the values of C_{10} and C_{01} indicated that, for both models, the numerical solution approached the experimental result when C_{10} was set to zero (Extreme-Mooney model). The values of C_{01} and G_∞ that gave the best representation of the peak force, and shape, of the experimental force-displacement curve, are given in Table 1.

Table 1 Material Coefficients for Extreme-Mooney and Linear Viscoelastic Material Models Representing Baseball Behavior During Compression

		Model B	Model C
Density	kg/m^3	7.42	7.42
	Extreme Mooney model		
C_{10}	Pa	0	0
C_{01}	Pa	$3.70e^6$	$2.56e^6$
	Linear viscoelastic model		
Long-term shear modulus (G_∞)	Pa	$3.81e^2$	$9.34e^1$
Instantaneous shear modulus (G_0)	Pa	$4.34e^4$	$2.89e^4$
Beta	s	0.0007	0.0007



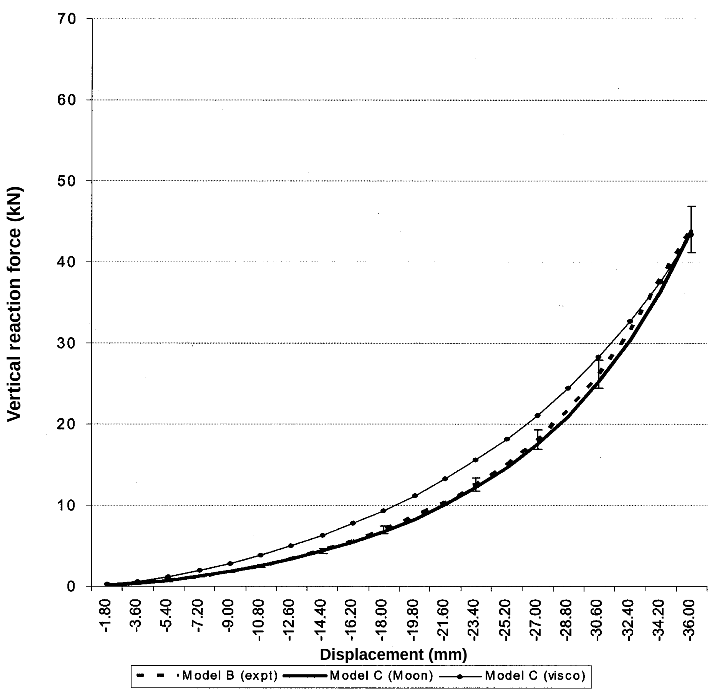


Figure 5 — The fit of Extreme-Mooney and linear viscoelastic models to experimental force-displacement curves (a) Model B, and (b) Model C.

Table 2 Results for Explicit Analysis of Model B and Model C Baseball Behavior Using Linear Viscoelastic Material Model

Velocity	m/s	13.4	20.1	26.6	33.5	40.5
MODEL B (Stiff baseball)						
Impact duration	s	$1.35e^3$	$1.18e^3$	$1.11e^3$	$1.02e^3$	$9.90e^4$
COR		0.636	0.662	0.678	0.687	0.693
Peak force	kN	4.6	7.8	11.2	15.1	19.5
Time of peak force	% impact duration	51.1	48.3	47.9	45.1	45.4
Max compression	m	0.0056	0.0081	0.0102	0.0126	0.0145
Max compression	% ball diameter	7.8	11.3	14.2	17.5	20.1
Time of max compression	% impact duration	51.1	50.8	52.3	54.8	55.7
Impulse of impact	N·s	3.2	4.8	6.4	8.2	9.9
MODEL C (Soft baseball)						
Impact duration	s	$1.50e^3$	$1.34e^3$	$1.24e^3$	$1.17e^3$	$1.14e^3$
COR		0.588	0.616	0.631	0.627	0.631
Peak force	kN	3.9	6.7	9.4	12.9	16.8
Time of peak force	% impact duration	51.3	47.8	44.5	43.7	42.9
Max compression	m	0.007	0.0099	0.0125	0.0151	0.0174
Max compression	% ball diameter	9.7	13.8	17.4	21.0	24.2
Time of max compression	% impact duration	51.3	52.2	54.8	56.4	56.1
Impulse of impact	N·s	3.1	4.7	6.2	7.9	9.6

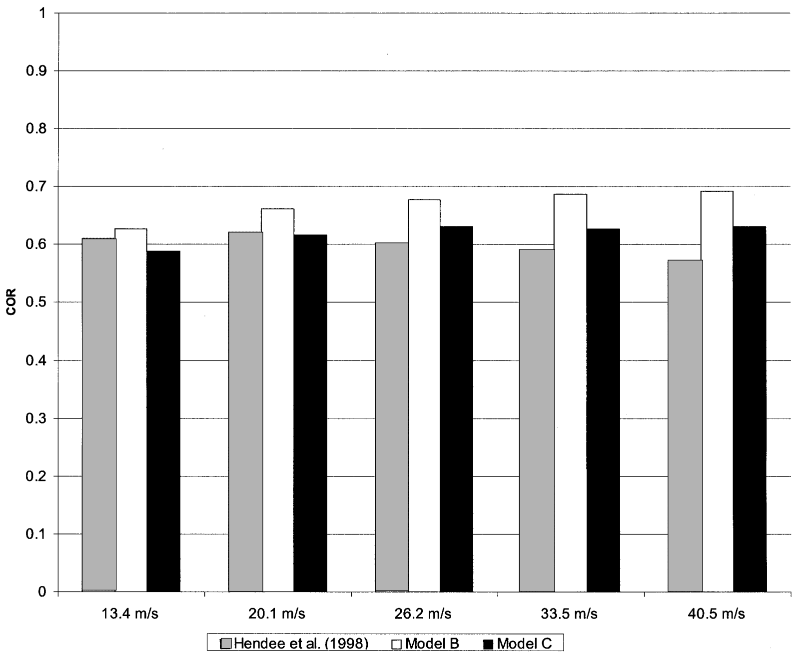


Figure 6 — COR for Models B and C across five velocities (13.4–40.2 ms^{-1}). The data of Hendee et al. (1998) for the stiffest baseball of 19 models tested is included for comparison.

The COR results obtained from explicit analysis ranged from 0.588 (Model C, 13.4 ms^{-1}) to 0.693 (Model B, 40.2 ms^{-1}) (Table 2). Comparison with the experimental data of Hendee et al. (1998) is shown in Figure 6. The COR data from the stiffest baseball of the 19 models tested by Hendee et al. was chosen for comparison to represent the maximal performance potential of baseballs. In that study, COR decreased marginally with increasing impact velocity. Our data indicates that COR increased slightly as pre-impact velocity increased for Model B, and remained approximately constant for Model C.

Ball Models B and C, while assigned the same value for β (0.007 s), had shear modulii that differed by approximately 33%. As impact speed increased, the COR of the two baseball models diverged, from 6.2% difference at 13.4 ms^{-1} to 9.0% at 40.2 ms^{-1}. As the velocity of impact increased, impact duration decreased for both Model B (36.4%) and Model C (31.6%). Similarly, for both balls, peak force increased with increasing impact velocity (428% for Model B and 427% for Model C). As velocity increased, peak force occurred earlier in the impact period, decreasing from 51% of this period to 45% for Model B, and 51% to 42% in Model C. The stiffer baseball (Model B) imparted greater impulse, an important variable related to momentum transfer, and thereby BEV, at all velocities.

An example of the deformation pattern experienced by the ball is given in Figure 7. The ball deformed up to 24.2% of its original diameter in Model C at 40.2 ms^{-1}, and 20.1% in Model B (Table 2). Model B demonstrated lower peak

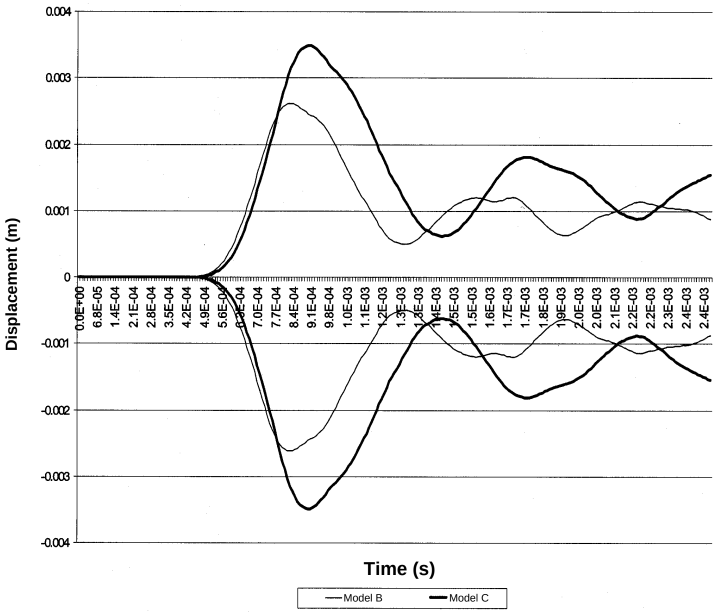


Figure 7 — Pattern of deformation of each baseball during the impact and immediate post-impact period. Deformation was measured from the displacement of two nodes at opposing poles on the lateral surface of the baseball.

compression at all velocities, although the difference decreased with increasing test velocity: Model B showed 20.0% less compression at 13.4 ms^{-1} compared to 16.7% at 40.2 ms^{-1}. Peak compression did not occur at the midpoint of the impact period in either ball model, and occurred later with increasing velocity for both balls. Peak compression occurred earlier in the impact period for the stiffer ball, particularly for the medium test velocities, in which peak compression occurred 2.5% earlier for Model B (52.3% of impact duration compared to 54.8%). This effect was less evident at the slowest and fastest pre-impact velocities (0.2% and 0.5% difference, respectively).

Discussion

A constitutive model based on linear viscoelasticity was developed to describe baseball response during compression. While the Extreme-Mooney model was suitable for description of the hyperelastic behavior of the ball during compression to 50% of ball diameter, this model was not available in ANSYS/LSDYNA 6.1 explicit software. A linear viscoelastic model was therefore adopted to account for the time-dependence of the ball materials. The model provides a numerical framework for further investigation of ball performance during high-speed impact with the baseball bat.

The results of the current analysis indicate roughly constant COR as pre-impact velocity increases. Hendee et al. (1998) reported a reduction in COR with increasing impact velocity, although this relationship was very slight for stiff baseballs. Because no indication of the standard deviation of COR measurements for the stiffest baseball was reported in Hendee's data, the slight downward trend for the very stiff ball may have been an aberration.

In this study, values for COR ranged between 0.588 and 0.693. The range of COR values obtained in previous analysis of ball behavior is large, possibly due to the variety of methods used in deriving material constants. Mustone and Sherwood (1998) developed a nonlinear elastic model for baseball behavior based on the Mooney-Rivlin formulation. COR of 0.710 was obtained, but the pre-impact velocity associated with this result, and values of C_{10} and C_{01}, were not reported. More seriously, damping was not factored into the ball material but was added as a global function, which effectively added damping to the entire impact analysis. In our research, the G_0, G_∞, and β terms of the linear viscoelastic model accounted for the decay properties of the material. Shenoy, Smith, and Axtell (2001) reported the value for G_0 as 41 MPa, to which our Model B value of 43.4 MPa compares very well. However, there are discrepancies in the values chosen for the time constant β, which should be chosen based on the duration of the impact event (Miller, 2000).

In our study, the best fit to the load-displacement data and COR values were obtained using a β value close to 1 ms, which is typical of the bat-ball impact period (Adair, 1997). The values chosen for β in the model of Shenoy et al. (2001) were two orders of magnitude larger, and may account for the disparity in COR values between their research (values of 0.450 at 20 ms^{-1} to 0.600 at 50 ms^{-1}) and the current work.

The current study provides information for baseball designers about dynamic ball response and the effect of material properties of the baseball on COR. A significant outcome from our experiments was the material model associated with the less-stiff baseball (Model C). This model had exhibited a markedly flatter force-displacement response and shear modulus approximately 33% less than Model B, resulting in greater peak compression, lower peak force, and longer impact duration. This information is important with regard to the growing interest in the performance of modified baseballs, which have been developed to reduce the severity of impact in the event of a player being struck by the ball—yet their performance characteristics remain relatively unknown. These balls are usually referred to as simply having "softer cores."

While such balls have experimentally shown decreased impact force and increased impact duration compared to traditional balls (Chauvin & Carlson, 1997; Heald & Pass, 1994; Hendee et al., 1998), mathematical description of the effect of mechanical changes to the ball materials has not been made until now. The present model gives a precise description of how a reduced load-displacement response equates to reduction of 33% in G_0, in addition to the reduced COR which is a direct measure of ball performance.

The process we have undertaken has value in a number of areas. First, we have provided experimental data for the response of the baseball to uniaxial compression to 50% of original diameter, and characterized this using a simple nonlinear elastic model. We have established the limitations of the explicit analysis package ANSYS/LSDYNA 6.1 for use of Mooney-Rivlin rubber-like material models. We then provide an alternative model which characterizes the time-dependence of the material behavior based on measures of both static and dynamic behavior in the compression and velocity range which may be expected for the ball during a baseball game. While further examination of the Extreme-Mooney hyperelastic model may be valuable, this linear viscoelastic model is suitable for immediate implementation in numerical analysis of bat-ball impact. This will allow further research of the performance characteristics of baseballs and the effect of changes to material parameters on COR and BEV.

References

Adair, R.K. (1997). *The physics of baseball* (2nd ed.). New York: Harper Collins.

ANSYS/LS-DYNA version 6.1 (2002). *Theoretical manual*. Cary, NC: SAS IP Inc.

Chauvin, D.J., & Carlson, L.E. (1997). A comparative test method for dynamic response of baseballs and softballs. In E.F. Hoerner & F.A. Cosgrove (Eds), *International Symposium on Safety in Baseball and Softball* (pp. 38-46). Philadelphia: American Society for Testing Materials.

Crisco, J.J., Hendee, S.P, & Greenwald, R.M. (1997). The influence of baseball modulus and mass on head and chest impacts: A theoretical study. *Medicine and Science in Sports and Exercise*, **29**, 26-36.

Greenwald, R.M., Penna, L.H., & Crisco, J.J. (2001). Differences in batted-ball speed with wood and aluminium baseball bats: A batting cage study. *Journal of Applied Biomechanics*, **17**, 241-252.

Heald, J. (1999). Reducing ball impact the easy way In G.S. Fleisig (Ed.), *Proceedings: 1999 Conference on Injuries in Baseball*. Birmingham, AL: American Sports Medicine Institute.

Heald, J.H., & Pass, D.A. (1994). Ball standards relevant to the risk of head injury. In E.F. Hoerner (Ed.), *Head and neck injury in sports* (pp. 223-238). Philadelphia: American Society for Testing Materials.

Hendee, S.P., Greenwald, R.M., & Crisco, J.J. (1998). Static and dynamic properties of various baseballs. *Journal of Applied Biomechanics*, **14**, 390-400.

Miller, K. (2000). Constitutive modelling of abdominal organs. *Journal of Biomechanics*, **33**, 367-373.

Mooney, M. (1940). A theory of large elastic deformation. *Journal of Applied Physics*, **11**, 582-592.

Mustone, T.J., & Sherwood, J.A. (1998, Sept. 21-22). Using LS-DYNA to characterize the performance of baseball bats. *5th International LS-DYNA Users Conference*, Southfield, MI. Livermore, CA: Livermore Software Technology Corp.

National Collegiate Athletic Association provisional standard for testing baseball bat performance." (1999, Sept. 27). *NCAA news release. http://*www.ncaa.org/releases/miscellaneous/1999092901ms.htm

Ogden, R.W. (1984). *Non-linear elastic deformations*. Chichester, UK: Ellis Horwood.

Shenoy, M.M., Smith, L.V., & Axtell, J.T. (2001). Performance assessment of wood, metal and composite bats. *Composite Structures*, **52**, 397-404.

Smith, L.V., Shenoy, M., & Axtell, J.T. (2000). Simulated composite baseball bat impacts using numerical and experimental techniques. In *Proceedings of the Society for Experimental Mechanics*, Spring Conference, Orlando, FL (pp. 5-8). Bethel, CT: Society for Experimental Mechanics.

Viano, D.C., Andrzejak, D.V., & King, A.I. (1992). Fatal chest injury by baseball impact in children: A brief review. *Clinical Journal of Sports Medicine*, **2**, 161-165.

"Wood-like performance recommended for nonwood bats." (1999, June 12). *NCAA news release*. http: //www.ncaa.org/releases/makepage.cgi/research/1999061201re.htm