A DYNAMIC FINITE ELEMENT ANALYSIS OF WOOD BASEBALL BATS

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INTRODUCTION

Subtle changes in the properties of a baseball bat can affect its performance and durability. Modern designs of metal and composite bats provide examples of bat properties taken to their extreme. Major League Baseball allows only wood bats to maintain the competitive balance between the pitcher and batter. There is also growing interest among amateur leagues to limit the performance of non-wood bats in the interest of player safety.

In this study, the dynamic interaction of a baseball and a wood bat are numerically modeled. The effects of bat stiffness and impact location on hit ball speed and bat stress are considered. The results from this and ongoing work will lead to more durable baseball bat designs and provide the technical information needed to develop a rational bat testing standard.

MATERIAL PROPERTIES

The properties of wood can vary widely within and especially between species. An optimized design must carefully balance tradeoffs between stiffness, strength and density, while considering non-homogeneity and the anisotropic response of wood. The mechanical properties of the bat and ball are non-linear and time dependent. Their dynamic response is approximated as linear elastic here, however, where the relative effects of bat stiffness and stress are of interest. The orthotropic nature of wood is considered, as is the variability of properties inherent in wood. A solid wood bat, made of northern white ash similar to that used in the major leagues, is examined. Nominal global modulus values were used for white ash in the axial, radial and transverse directions of 12.4, 1.17, and 1.31 GPa (1.8, 0.17 and 0.19 Msi) respectively.

The elastic modulus of a standard baseball was determined from a quasi-static load displacement curve. (Adair, 1990) A linear elastic modulus of 69 MPa (10 ksi) was found for the ball from the non-linear load displacement data by considering the herzian type contact stresses between the bat and ball (Timoshenko and Goodier, 1970).

BOUNDARY CONDITIONS

The dynamic interactions of a baseball and bat are complex and depend on factors that are often difficult to quantify. Simplifying assumptions are necessary to cast the problem in a solvable form. Reducing the complexity of the problem in this way inevitably hinders the comparison with actual field measurements. Sensitivity studies can nevertheless provide insight concerning the contribution of the numerous variables involved.

The dynamic interactions of the bat and ball were numerically modeled using LS-Dyna 3D (Livermore Software Technology Corp., Livermore, Ca.). The model consisted of 1024, 8 noded brick elements. Contact between the bat and ball was determined using sliding contact elements that accounted for static and dynamic friction. The explicit solution was obtained through iteration, where the solution time step was determined from the relative difference in stiffness between the bat and ball. The bat was given an initial rotational velocity, centered 150 mm (6 inches) from the knob, of 31 m/s (70 mph) measured at its center of mass. The ball was given an initial linear velocity of 31 m/s (70 mph) in the opposite direction. The center of the ball and bat were coplanar and the bat contacted the ball as its length was normal to the ball velocity direction. The bat was unrestrained during and after ball impact, which may be representative of an actual swing (Weyrich, et. al, 1988).

RESULTS

The model was run using an 864 mm (34 inch) long, 992 gram (35 ounce) solid wood baseball bat, with a barrel and handle diameter of 63 mm and 25 mm (2.5 in and 1 in) respectively. The effect of ball impact location on the maximum bending bat stress and hit ball speed is presented in Fig. 1. The location of the center of percussion (COP) is evident from the figure, as the location producing the highest hit ball speed, and the lowest bat stress. The coefficient of restitution for ball bat impacts ranges between 0.5 and 0.6 (Adair, 1990). The hit ball velocities of Fig 1 are in good agreement with field measurements if this factor is applied. Ball location is observed to affect bat stress significantly, where a ball hit 125 mm (5 inches) off the COP increases the bat stress by a factor of 4.

The longitudinal bat stress is plotted as a function of wood modulus in Fig. 2 for various ball impact locations. (The radial and transverse moduli were scaled proportional to the axial modulus.) Bat stress is observed to generally increase with wood stiffness, although the dependence is non-linear, and varies with ball impact location. Bat stress from ball impacts near the COP, for instance, are nearly independent of bat stiffness, while the stress from hits ±125 mm (±5 inches) from this location increase with stiffness. The trend is less clear at ±50 mm (±2 inches) from the COP, however.

SUMMARY

The dynamic interaction of a solid wood baseball bat and ball was numerically modeled. Results of the model were verified with published measurements of the COP location and hit ball speed. The results presented here indicate that bat stress is highly dependent on impact location and can increase with stiffness as well. The properties of a wood bat must, therefore, be carefully selected if bat stiffness is to be increased without reducing bat durability.

Ongoing work includes the evaluation of different wood species, laminating technologies, pitched ball speed, and bat motion. This work will help to improve product development and bat performance testing standards.

ACKNOWLEDGEMENTS

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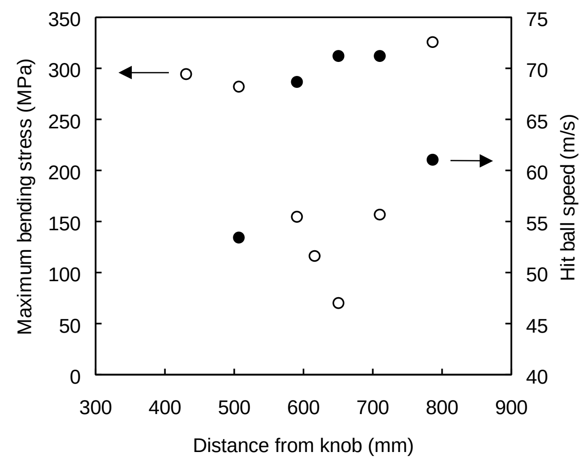

Fig. 1. Maximum bending stress and hit ball speed as a function of a perfectly elastic ball-bat impact.

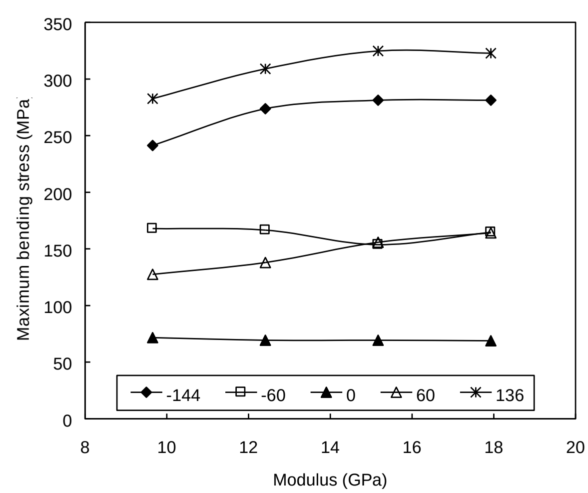

Fig. 2. Maximum bending stress as a function of wood stiffness for various impact locations (mm) relative to the center of percussion.