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Finite Element Simulation of Ball-On-Tennis Racket Impacts Using ABAQUS/CAE

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Abstract: - The submitted paper describes development of tennis ball -racket models with ABAQUS/CAE software that accurately simulate ball-on-tennis racket impacts. The racket model can be implemented in ABAQUS Explicit analysis software in order to study the mechanical properties of the racket, especially the impact, string bed of the racket and transverse to frame. These models are being used to investigate the individual and combined effects of many different design variables and to develop insights for improving the design of tennis rackets. The finite element code ABAQUS Explicit was mainly employed in the study of sensitivity on the simulations to step time, material properties, mesh characteristics, and (COF) coefficient of friction. The output of this simulation shows displacement (Elastic properties) which in turn is the mechanical behavior of the tennis ball and string bed is appropriate and agrees with the objectives in the literature review.

Keywords: *- ABAQUS/CAE software, COF, impact, mechanical behavior, Tennis ball –racket*

I. INTRODUCTION

In the real world there are physical scenarios related to impact problems which needs engineering solution using numerical methods. Tennis ball –racket is among a few scenarios which needs reengineering. Here this paper investigates how we can design efficient and tennis racket with comfortable condition this can be done through ABAQUS code by considering the elastic properties of the ball and the string bed and the coefficient of friction between the ball and the racket, for desired solution here the mesh characteristics is considered.

Detailed structural models of the tennis ball –racket are required to gain more insight into the impact dynamics of racket balls. This study introduced the development of a detailed FE model for the structural analysis of racket balls. The models were calibrated against literature data obtained from research developed for this purpose, including drop tests and high speed impact tests. Modern predictive models show that improvements in tennis rackets — which primarily focus on reduced mass and increased structural stiffness — allow a player to serve 17.5 percent faster using modern equipment compared to what was available in 1870 [1]. Tennis racket has been significantly changed, despite the play's rules are substantially the same, because new materials and technologies have been widely used in the equipment manufacturing during the last two decades? This freedom creates some troubles to the designers, which now must precisely define the project objectives and identify the key mechanical parameters to be tuned for achieving such objectives [3].Researchers scanned a racket with a laser to produce a surface model that reflected the geometry of a real racket. They used a linear elastic material model for the racket's frame, which was meshed with 27,410 shell elements. The racket model included an interwoven string bed that had a linear elastic material model. The string bed was no rigid, and the individual strings had the capability to move where they intercept other strings [2].

Fig.1 shows the tennis ball with racket

II. LITERATURE REVIEW

The tennis racket design had many improvements in last few years. The racket heads have grown larger, on frames that have become lighter. The racket frame and strings are of great importance for the player performance. The racket model can be implemented in Ansys analysis software in order to study the mechanical properties of the racket, especially the impact, vibration between tennis ball, string bed of the racket and transverse to frame. Tennis racket has been significantly changed, despite the play's rules are substantially the same, because new materials and technologies have been widely used in the equipment manufacturing during the last two decades? This freedom creates some troubles to the designers, which now must precisely define the project objectives and identify the key mechanical parameters to be tuned for achieving such objectives **.** The finite element method (FEM), which analyses the elastic behavior of rackets under static conditions, providing chances for remarkably differentiation of rackets performances (Glitsch,1980). Also, considering both the racket and ball (Hatze, 2002), acquire the information on the time dependent three-dimensional positions and orientations of racket and ball. The model of the racket with different damp has calculated by finite element method and testified the reliability using instrument (Buechler, 1999). But a great deal of racket model research in free handle condition and the string hadn't been taken as important as racket. Today's tennis racquets are a showcase of high tech materials and engineering . This knowledge can be used by a tennis player to choose the best racket for him and to improve the tennis techniques. Understanding these design aspects is also important to anyone with an interest in modern technology [2].Matthew Vokoun described in his work the design aspects of Tennis Rackets the two main design aspects of tennis rackets, which are classified in external and internal design aspects. The external design aspects consist in: strings, head size, and beam size. The internal design aspects are material type, weight, and balance **[1]**. The strings characteristics such as elongation, tension, and pattern density are of great importance in stroke production. The head size provides the desired power: a larger head provides more power (longer head) or a better control (wider head). The beam size (racket's cross section) influences the racket's stiffness and power. Ball impact behavior can be described in terms of coefficient of restitution (energy dissipated in an impact) and stiffness (force and deformation of a ball during impact). Official regulatory standards tend not to stipulate the material or construction for use in the ball, instead specifying the required range of COR and stiffness characteristics. The International Tennis Federation have reported that of the 272 brands submitted in 2006, 5.5% had failed. Similar figures have been reported from 2005 (240 submitted: 7% failed). The most common failures have been from rebound and deformation testing, with size and mass tests having the highest pass rates **[2]**.

University researchers used ANSYS LS-DYNA explicit dynamics software to simulate tennis racket–ball impacts. The software simulates short-duration events with severe loadings and large deformations, thus helping researchers to understand what happens during crashes, explosions and metal forming operations. LS-DYNA is available within the ANSYS Workbench environment, which provides extensive CAD interfaces, automatic meshing, integration with other simulation tools and design optimization The research team evaluated the COF at 0.0, 0.2, 0.4, 0.5, 0.6, 0.7, 0.8 and 1. The simulation projected the tennis ball onto an initially stationary, freely suspended racket. Engineers compared simulation results to the International Tennis Federation's custom racket impact machine, designed to simulate non spinning impacts between a tennis ball and a racket at a range of velocities and locations on the long axis of the string bed. **[3]**.A modelisation done by seydel [4] of the trajectory of the tt-ball in air was finished 1990.the rebound of the ball on the table was modelled by Durey [5]1987. Here we summarize our actual physical research done in Cachan (Paris) in the laboratory of Alain Durey concerning the impact of the tt-ball on the racket. **[6]** Researchers used simulation to investigate the effects of changing the COF between the strings and the balls. The results showed that with low rebound angles (relative to racket face normal), the COF did not have a major impact on the ball's rebound characteristics. Examination of simulation results showed that the ball was effectively rolling off the string bed, so coefficient of friction made little difference. The COF has a larger impact if the ball is sliding or overspinning on the racket at the end of the impact.

III. METHODOLOGY

3.1. Finite Element Modeling

The tennis ball-racket impact scenario is modeled and simulated using ABAQUS/CAE. Before modeling the part the frame and the strings are made in the sketcher which when assembled gives the racket.

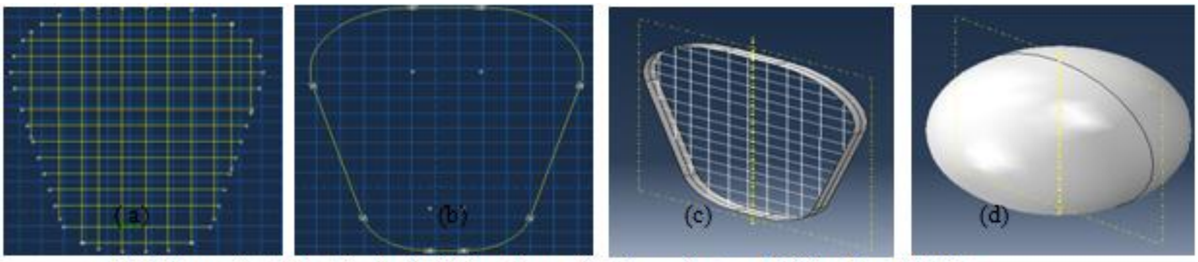


Fig2.Shows that (a) string bed, (b) the frame, (c) the racket and (d) the Tennis Ball

TABLE 1 shows the material properties assigned for each models

Materials	Properties	Denstiy (kg/m^3)	Young's Modulus (pa)		Poisson's Ratio
Frame	Elastic	0.001	10000000000		0
String	Elastic	0.000107	1000000		0
Ball	Hyper elastic	0.0001	Polynomial Coefficients		
			C10	C01	D1
			100	25	0.0001

The the racket and the tennis ball is assembeled in its initial position and the meshing are done for both the ball and the racket. the mesh control for the ball with element shape Quadrilateral dominated with free technique.but some research and experience shows that triangular mesh comes with better solution than others but the analysis time will increase. The element type is explicit and geometric order is linear with family of shell S4R: A 4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strains.

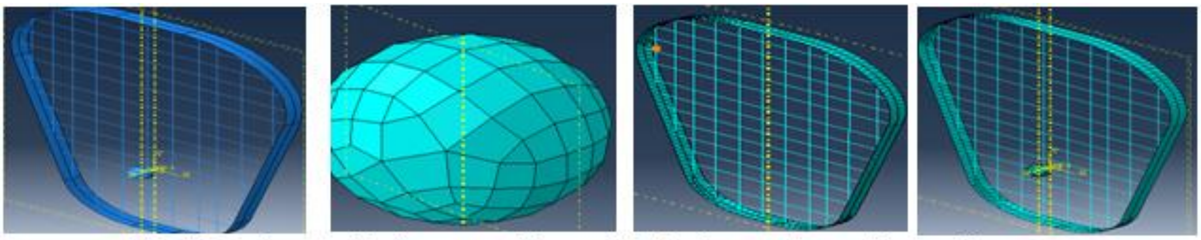


Fig3. Shows the assembly instance and the mesh for both part and assembly model

IV. RESULT AND DISCUSSION

The result from the numerical method that is finite element method which simulated the real tennis ball racket scenario shows that the time step and the mesh characteristics as well as the COF shows that all this factors will affect the final solution and more importantly this result shows ABAQUS/CAE is the powerful finite elements analysis tool for solving this kind of real world problems . In the figures 4 below the shows the displacement of the ball and the racket strings. And in figure 5 the velocity of the Ball at six different step time.

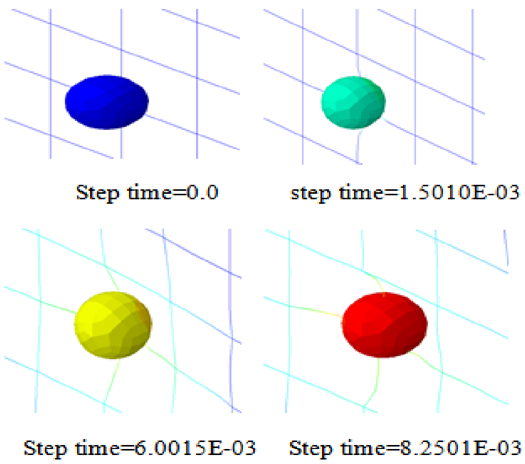


Fig4. shows the displacement of the ball and string bed

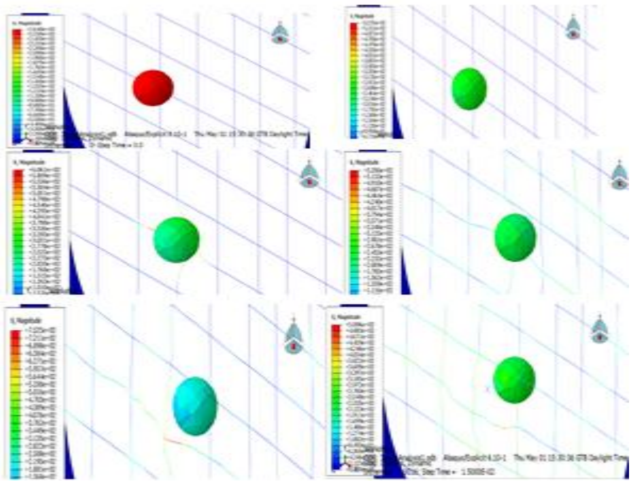
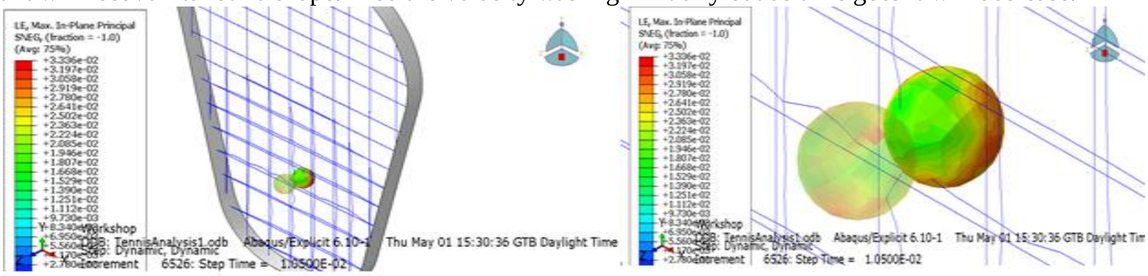


Fig5. shows the velocity of the ball

As it is observed from the above impact simulation the displacement of the ball will increase and because of the ball have important mechanical behavior (Elastic properties) it will rebound after the impact on the string bed and it will recover its round shape. Also the velocity was high initially but as time goes it will decrease.



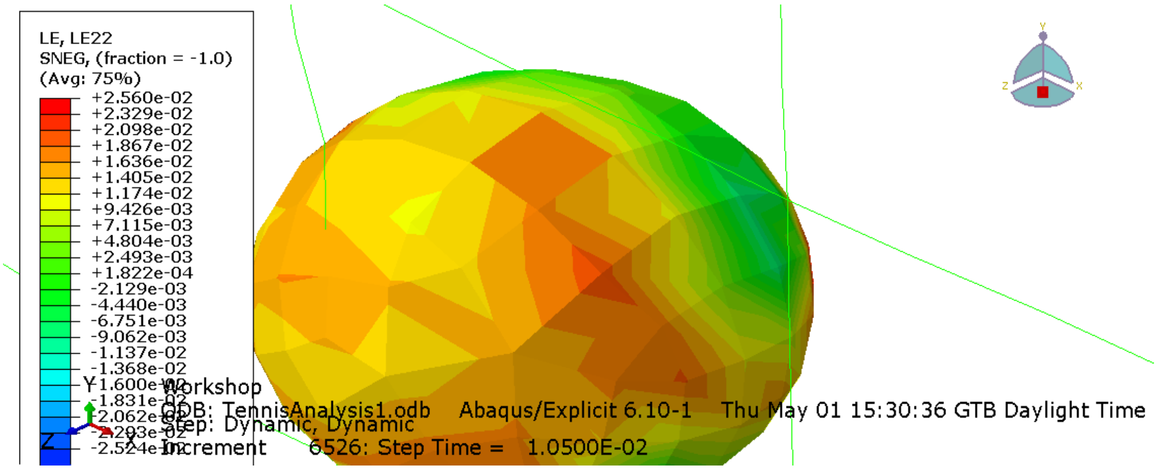


Fig6. Shows the max in plane Logarithmic strain at step time=1.0500E-02

The logarithmic strain shows the deformation of the ball as the time increases. From the above figures the maximum in plane principal LE will occur at step time of 1.0500E-02.Let us know see the reaction of the string bed towards the impact of the ball. To see this displacement U is considered. And since the string bed is designed for elastic materials as shown in the figure below it doesn't fail plastically.

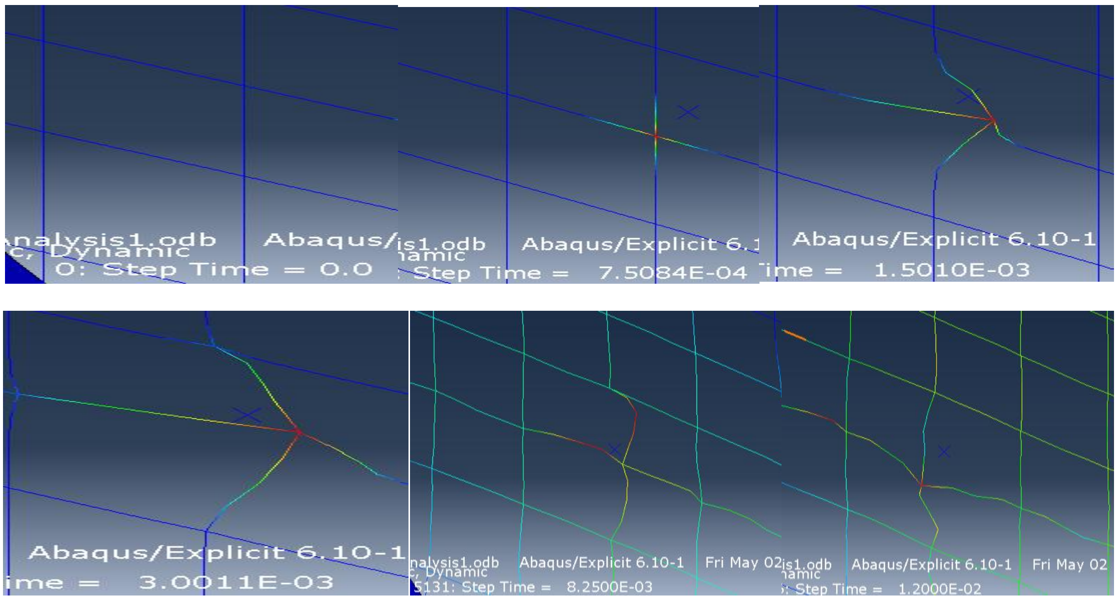


Fig7. Shows the deformation of the string bed on displacement contours at different time step

The following figures are the result drawn from ABAQUS Visualization module as it is observed below the outcome show significant mechanical behavior of the string bed in figure (a). Here the displacement increases dramatically and suddenly regain it original shape. As expected the acceleration as well as the velocity will decrease and increase after rebound from the racket.

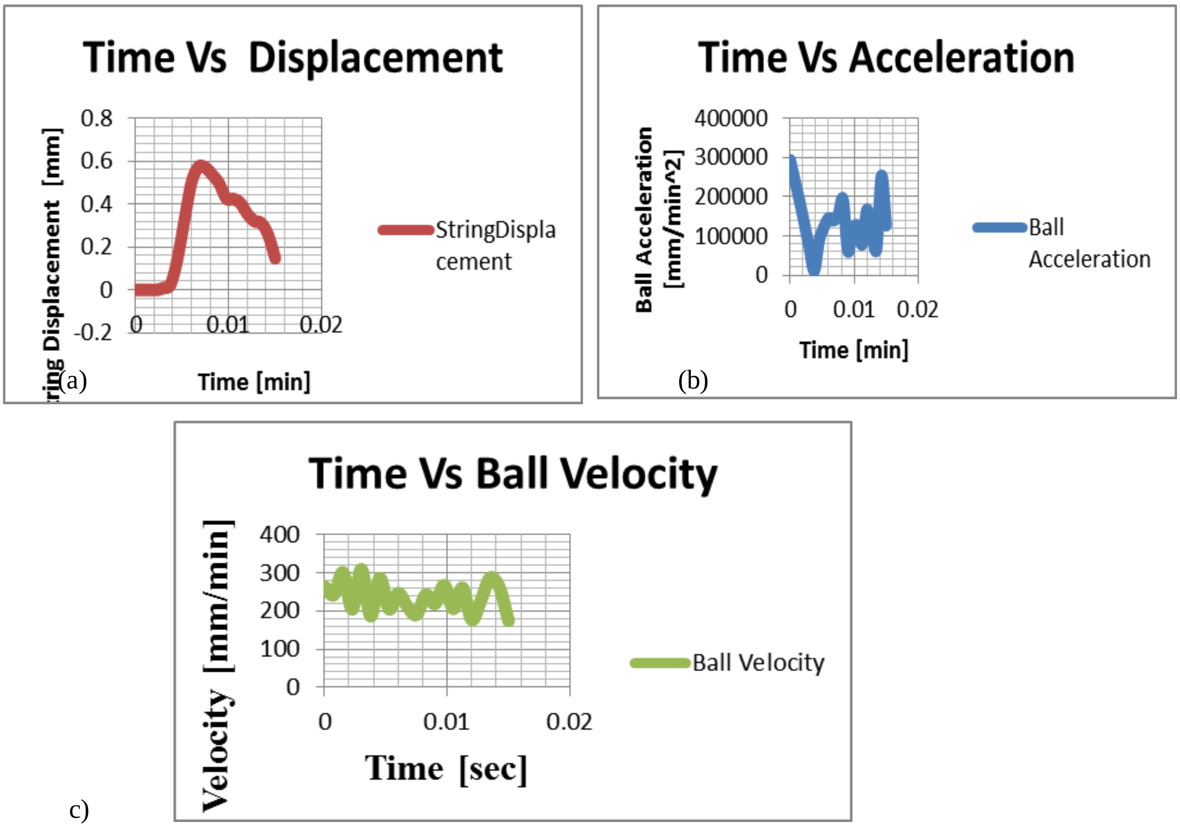


Fig8. Shows (a) String bed displacement, (b) Acceleration of the Ball, (c) Velocity of the Ball

V. CONCLUSION

This paper investigates the effect of mesh characteristics, Coefficient of friction (COF), material properties, and step time on the tennis racket impact scenario. The finite element code ABAQUS Explicit was mainly employed in the study of sensitivity of the simulations to step time, material properties, mesh characteristics, and (COF) coefficient of friction. The output of this simulation shows displacement (Elastic properties) which in turn is the mechanical behavior of the tennis ball and string bed is appropriate and agrees with the objectives in the literature review. Here as the step time decrease the solution become more accurate and the material properties show significant result on the racket so it opens new design innovation for this sport regardless of the rules and there by improve the performance of the players. Finally it is worth nothing without mentioning ABAQUS code is powerful tool for such kind of problems.

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