Introduction

Takraw balls are used in *sepak takraw* games which are one of the most popular traditional games in Southeast Asian region. In this game, three players on each side of a 5-foot high net, get three chances to kick the ball mainly by the use of the head and legs or other parts of the body (except for both hands or arms) to return the ball to the opposing team. Recently, the International Sepak takraw Federation (ISTAF) has been endeavouring to bring this traditional game into the Olympic games by the year 2020 (*Utusan Malaysia Online*, 2009). The traditional *takraw* ball is manufactured by conventionally weaving split rattan strips into a spherical basket. Modern *takraw* balls are manufactured by forming strips of plastics materials into interwoven hoop. These interwoven hoops form 12 holes and 30 intersections.

The design of a solid-ball in various sports equipment, such as for soccer ball, softball, golf, and also *takraw* ball, is a complicated phenomenon and in the literature there have been attempts to analyze this complicated phenomenon due to several reasons. For example, due to safety reasons, the design of a soccer ball should be soft enough to avoid injuries caused by contact between ball and head (CPSC, 1995-2002). However the ball should not be too soft in order to maintain the performance of the game. A study (Taha, Iskandar & Hilma, 2008) found that a *takraw* ball made of plastic impregnated with rubber to soften the surface of the ball has a higher probability of head concussion compared to a ball made without impregnated rubber. This higher probability of concussion is because the rubber impregnated ball travels at higher velocity than the normal one.

Several studies have modeled balls using Finite Element Analysis (FEA) to investigate this complicated phenomenon under a given set of boundary conditions (Smith & Duris, 2009; Tanaka, Sato, Oodaira, Teranishi & Ujihashi 2006; Price, Jones & Harland, 2006). When the boundary conditions are defined, the FE models can be used to predict impact responses of the head (Crisco, 1997) and other human body parts or can be used to study improvement of sport equipments such as baseball bats (Bathke, 1998; Mustone & Sherwood, 1998). However, these approaches still require validation with experimental test results.

The purpose of this study is to construct a Finite-Element (FE) model of a *takraw* ball in particular for normal impact simulation on flat surfaces under low speed conditions. Two FE models were developed to observe their dynamics in term of impact force, contact time, Coefficient of Restitution

(COR) and deformation of the ball. The first model consists of a single solid hollow ball with 12 pentagon holes and the second model consists of six center strips and 12 side edge strips of extrusion hoops to form 12 pentagon holes and 270 cross-sections. Prior to FE modeling, the mechanical properties of the *takraw* ball were defined from the studies by Ahmad, Taha, Ujihashi & Tanaka (2009). In this studies free fall drop tests were conducted to measure the actual dynamic behavior of the *takraw* ball. Details of this study will be explain in the next section. The experimental results are compared with the two FE models. The results of the study seek to demonstrate that an FE model of the *takraw* ball can be use as a predictive design tool in order to assist in the product development process of *sepak takraw* balls and accessories such as shoes, and impact study on the human head or any other part of the body.

Free fall dropped testing

The experiment was performed using the apparatus illustrated in Figure 1. Two *takraw* balls (with an average weight of 177g) were dropped vertically under three different conditions of drop heights (i.e. at h = 1.5m, 2.0m, and 2.5m). The different heights will result in different ball velocities on impact. These ball velocities were measured using a motion analysis software and was found to be close to velocities measured using a laser light.

The dynamic behaviour before, during and after impact were recorded using a high-speed video camera at a speed of 500 frame per second. The normal impact force histories were recorded by a using force plate synchronized with the video capture. In order to get consistent data, the balls were dropped with the same face at their initial positions.

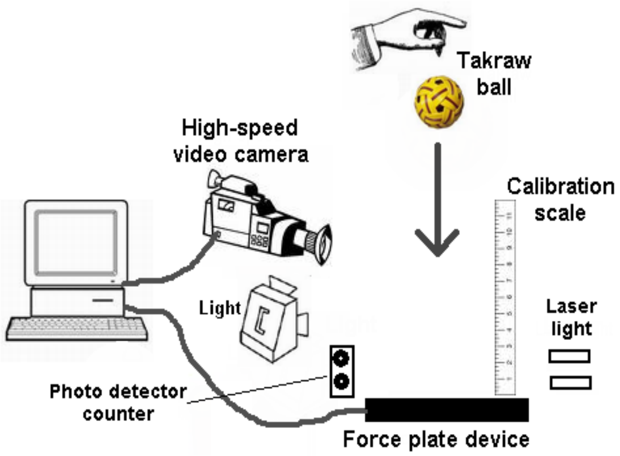

Figure 1: Experimental set-up by Ahmad, Taha, Ujihashi & Tanaka (2009)

Contruction of the FE model of the *Takraw* ball

Two FE models of the *takraw* ball were constructed based on the existing geometry of the ball which is hollow with 12 pentagon holes. The outer diameter and inner diameter of the balls are 132mm and 123mm, respectively. The ball models are composed of four-node of linear tetrahedron elements.

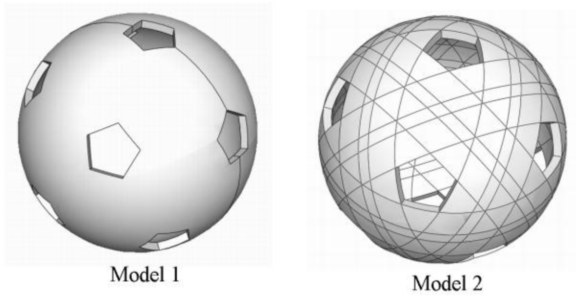

Figure 2: Two Finite Element models of the *takraw* ball

The geometrical constructions of ball models (Figure 2) were developed using two different techniques. In the first model (Model 1), the ball was constructed with a single solid revolve extrusion and with 12 cutting extrusion of the pentagon holes. For the second model (Model 2), the ball was constructed with a solid revolve extrusion to formed six center strip hoops and 12 side edge hoops. Then these hoops were assembled to form 12 pentagon holes and 270 cross-section parts.

In this study, the material model of the ball which is made of polyolefin blend (Lorpipatana & Lorhpipat, 1995) is expressed as a linear elastic model. The density of the ball was estimated from the weight of the ball divided by the total volume of the FE model. The modulus of elasticity and Poisson's ratio of the material models were defined from the studies by Ahmad et al. (2009). The maximum impact forces, maximum normal deformations of the ball and rebound velocities were obtained from the simulation. The commercial FE software ABAQUS/Explicit version 6.7 was used for the computer simulation (ABAQUS User Manual Version 6.7).

Results and discussion

Maximum ball deformation

In this study the maximum ball deformation during impact focuses on normal deformation. The maximum normal (d_n) is calculated using the following equations:

$$d_n = 100|D_n - D_o| / D_o \qquad (1)$$

where D_o and D_n are the initial ball diameter and maximum ball span normal to the flat surface respectively. The initial ball diameter was determined from three ball images prior to the ball impact while the maximum ball span in normal deformation was selected from the ball image with the maximum ball deformation.

Figure 3 shows the maximum normal deformation as a function of the inbound velocity, where the dotted lines (the result from FE models) and the solid line (the result from experimental) were determined using the least squares method. Here the maximum ball deformation in the normal direction increases with the ball velocity for both experimental and FE model. However the rate of increment of the maximum ball deformation of both FE models are slightly less than the experimental results. This means that both FE models have slightly harder material properties compared with the actual physical hardness of the *takraw* ball. The simulation results also indicate that FE model 2 is harder than FE Model 1.

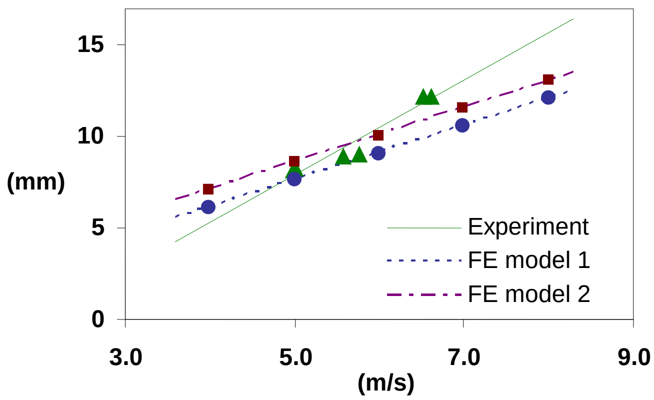

Figure 3: Maximum normal ball deformation (mm) for both experimental and both FEA simulation results as a function of inbound ball velocity (m/s)

Contact time of the ball

In the experimental analysis, the contact time between the ball and the flat surface was estimated from the first and final contact images. If an image having a small deformation at both first and final contact then the images were corrected by using an image just before and after the contact. Figure 4 shows the contact time of the ball as a function of inbound ball velocity for the experimental and both FE models results. From the results only FE model 1 shows the same trend with the experimental result where the contact time increases with the inbound velocity of the ball. FE model 2 shows decreasing contact time with the inbound velocity of the ball. However the contact time for both FE models results are less than the experimental results especially at high inbound ball velocities. This could be because the FE models have greater hardness than the actual *takraw* ball.

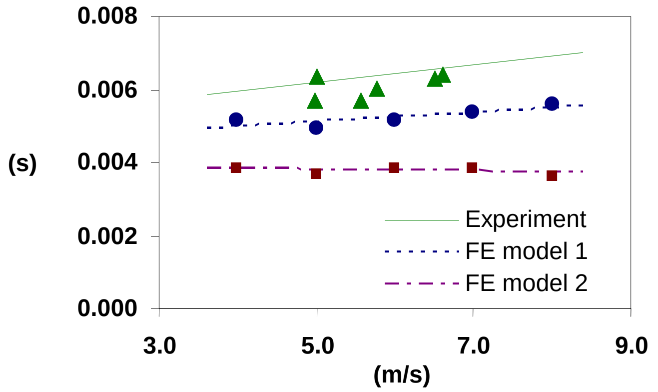

Figure 4: Contact time (s) of the ball during impact as a function of inbound ball velocity (m/s).

Coefficient of Restitution (COR)

The coefficient of restitution (COR) of the ball is calculated as the ratio of the velocity after the ball impact to that of the velocity before the ball impact (Farkas & Ramsier, 2006). The COR from the FE models are compared with the experimental result as a function of inbound ball velocity (Figure 5). Both FE models produced 22 percent higher COR compared with the experimental result. The higher COR value of the FE model can be ascribe to less energy being lost even though the ball deformation from the experiment and FE simulation are almost similar. Therefore, the FE model of the *takraw* ball needs to be improved by considering other aspects of energy lost during impact.

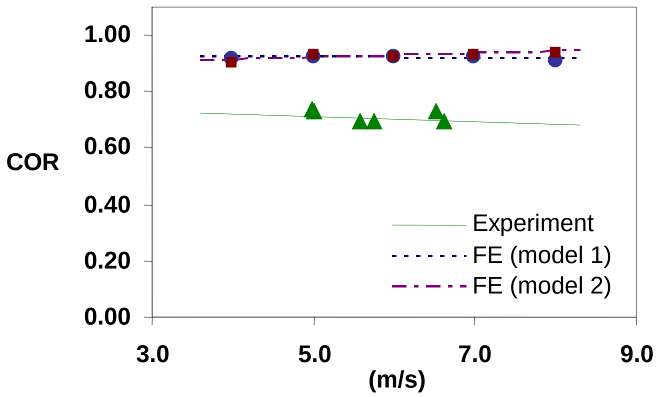

Figure 5: Coefficient of restitution (COR) of the ball as a function of inbound velocity (m/s).

Impact force during contact time

Figure 6 shows the comparison between the experimental and FE model simulation results for the maximum impact force as a function of inbound velocity. Here both FE model results shows incresing maximum impact loads with increasing inbound ball velocities and a similar result is also seen from the experimental results. The results also indicate that the FE models showed 20 percent higher impact force compared with the experimental results. This could be attributed to the FE model having a higher body stiffness design. Further study need to done to determine how the ball model can be adjusted to achieve appropriate impact force and ball deformation.

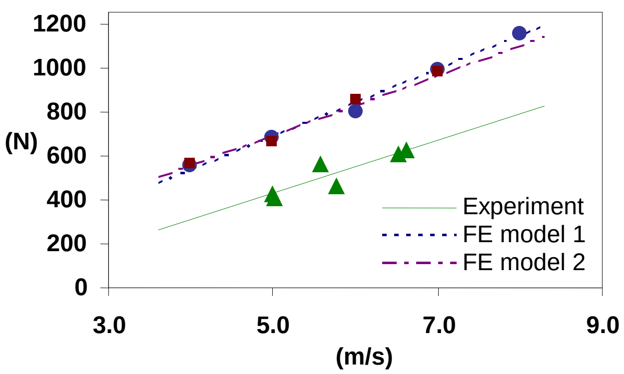

Figure 6: Maximum impact force (N) as a function of inbound ball velocity (m/s).

Conclusion

In this study two FE models were developed to compare the dynamic behavior of *takraw* balls with experimental results. The first model is made up a single solid revolve extrusion with 12 cutting extrusion of the pentagon holes. The second model is constructed from a solid revolve extrusion of six center strip hoops and 12 side edge hoops to formed 12 pentagon holes and 270 cross-section parts. Both models used a linear elastic model for the material properties and four-node of linear tetrahedron elements.

All the impact force, ball deformation, contact time, and coefficient of restitution (COR) were determined as a function of inbound ball velocities. Both FE models have provided evidence that the dynamic behavior of the *takraw* ball are influenced by the effects of ball velocities before and after impact. It was found that only the ball deformation and contact time could be different independently. It was observed, however, that the FE models produced slightly greater stiffness than the experimental results. Therefore, further improvement need to be done by taking into consideration the nonlinearity of the *takraw* ball under large deformation as well as at the high velocity impact.

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