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AN EXPERIMENTAL STUDY OF THE IMPACT OF A SEPAK TAKRAW BALL ON A FLAT SURFACE

N. AHMAD[1], Z. TAHA[1], S. UJIHASHI[2], AND K. TANAKA[2]
[1]*Centre for Product Design & Manufacturing, Faculty of Engineering, University Malaya, 50603 Kuala Lumpur Malaysia*
E-mail: norhafizan@um..edu.my, zahari_taha@um.edu.my

[2]*Department of Mechanical & Environmental Informatics, Graduate School of Information Science and Engineering, Tokyo Institute of Technology, 152-8552, Japan*
E-mail: ujihashi@mei.titech.ac.jp, ktanaka@mei.titech.ac.jp

The takraw ball is a very unique interwoven ball used in the action game of sepak takraw. To date there has been no studies on the dynamic behavior and mechanical properties of the takraw ball. The purpose of this study is to predict the dynamic behavior and mechanical properties of the takraw ball in particular of normal impact on flat surfaces at low speeds. Two methods are employed to measure the dynamics behavior and mechanical properties of the takraw ball. The impact force, contact time, coefficient of restitution, deformation of the ball, inbound and rebound velocity were measured by using two dimensional motion analysis of high-speed video data and force plate data. Then, a finite element (FE) model of the homogeneous takraw ball is constructed, based on the experimental results. This FE model is used to predict modulus elasticity and Poisson ratio of the takraw ball. The FE analysis solution of the ball model was found to be reasonable close with the experimental results. However further improvement need to be done by taking into consideration the nonlinearity of the takraw ball under large deformation as well as at high impact velocity.

1 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 use of the head and leg 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 endeavoring to bring this traditional game into the Olympic game by the year 2020 (Utusan 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 pentagon holes and 90 intersections. To date there has been no studies on the dynamic behavior and mechanical properties of the takraw ball especially during its impact on a particular surfaces.

In similar sports several methods have been used to investigate the dynamic behavior of the balls on impact. The most popular method is the high-speed video analysis system (Arakawa *et al.*, 2006, Smith & Duris, 2009) synchronized with force gauge sensors (Arakawa *et al.*, 2008, Tanaka *et al.*, 2006). In this method the deformation of the ball, coefficient of restitution (COR), rebound velocity, contact time and normal impact force as a function of the of the impact velocity are measured. Detail of this method used in this study, will be explained in the next sections.

With the advancement of computer hardware and software, a new approach has come into forefront. This approach called finite element analysis (FEA) allows the investigation of complex ball structure under a given set of boundary conditions (Smith & Duris, 2009, Tanaka *et al.*, 2006, Price *et al.*, 2006). When these boundary conditions are defined the FE models can predict mechanical properties of the ball either in linear elastic models or in non-linear elastic models such as viscoelasticity and hyperelastic model. However this approach still requires validation with experimental test results.

The purpose of this study is to predict the dynamic behavior and mechanical properties of a takraw ball in particularly during normal impact on flat surfaces at low speeds. The maximum impact force and ball deformation, inbound and rebound velocities, coefficient of restitution (COR) and contact time were investigated. The work presented in here also focused on the development of a homogenous hollow ball modeling methodology using FEA. A linear elastic model of the FE model of the ball was constructed by varying the individual materials constants. The results of the experiment seek to demonstrate that an FE model of the takraw ball provides a predictive design tool in order to assist in the product development process and impact study on the human head and foot as well as for takraw shoes.

2 Experimental methods

Two takraw balls (with an average weight of 177g) were dropped vertically under four different conditions: three from different drop heights (i.e. at *h* = 1.5m, 2.0m, and 2.5m) and one was *forced dropped.* The different heights as well as the force drop condition 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 laser light.

The dynamic behavior 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 the initial positions.

3 FE model of the takraw ball

A simplified homogenous FE model of the takraw ball was constructed based on the existing geometry of the ball which is hollow with twelve pentagon holes. The outer diameter and inner diameter of the hollow ball are 132mm and 123mm, respectively. The ball model is composed of eight-node of linear hexahedron elements (Fig 1).

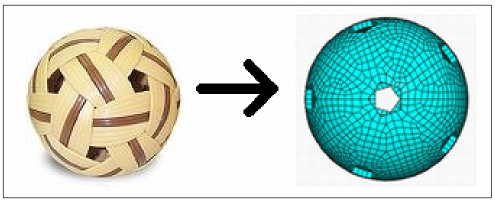

Figure 1. Simplified FE model of the takraw ball

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 ball divided by the total volume of the FE model. The modulus of elasticity and Poisson's ratio of the material models varies from 70 to 130 MPa (*da* Silva *et al.*, 2002) and 0.35 to 0.50 (Tschoegl *et al.*, 2002), respectively. 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: Analysis User's Manual).

4 FE model of the takraw ball

High-speed video images

Figure 2 shows six images illustrating the dynamic contact behavior of the ball, where (a) is the image recorded before impact, (b) show the first contact with a small deformation, (c) and (d) show the compression or restitution period, (e) indicate the final contact prior to rebounding, and (f) show the ball after the impact. The inbound and rebound velocity, ball deformation and contact time were measured by using motion analysis software (DIGIMAN, copyright by Dr. Zahari Taha). The results found that the inbound velocities of the ball increase with increasing height as well as the rebound velocities. Similar results have reported in Taha *et al*. (2008) studied. The rebound velocities are less than the inbound velocities. The ratio between inbound and rebound velocities will be explained in the next sections.

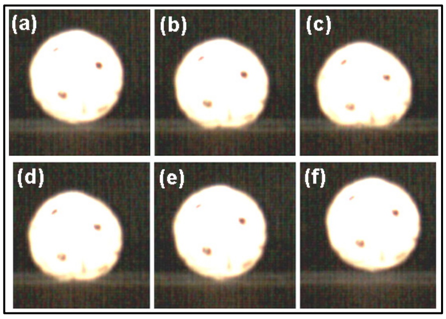

Figure 2. Six video images taking from before, during and after the ball impact at 2.5m height

Finite element analysis

The volume of the FE model of homogenous takraw ball is about 199.2E – 6 m^3, thus the density of the ball will be 890 kg/m^3. In order to ensure that dynamic behavior of simulation results are close to those experimental results a number of normal impacts against a rigid flat surface are simulated based on the range of elasticity modulus and Poisson's ratio as described previously.

Initially the input velocity of the ball just before the impact which is used for constructing the FE model of the ball was 7 m/s. The results of final mechanical properties to construct FE model of the takraw ball are showed in Table 1. The different between experimental and FEA simulation results for the maximum ball deformation and impact force are 12% and 15%, respectively. The determined values of those material constants are acceptable when simulate with other input velocities i.e. at 5, 6, 8, and 9 m/s.

Elasticity Modulus (MPa)	90	
Poisson Ratio	0.48	
Density (kg/m^3)	890	
Max ball deformation (mm)	Experiment	11.4
	FEA	12.2
Max impact force (N)	Experiment	601
	FEA	690

Table 1. Material properties of the constructed FE model and their results of ball deformation and impact force at inbound velocity of FE ball (7 m/s)

Maximum ball deformation

To analyze the maximum ball deformation quantitatively, the maximum normal (d_n) and tangential (d_t) deformation ratios were calculated using the following equations:

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

$$d_t = 100|D_t - D_o|/D_o \cdots\cdots\cdots(2)$$

Where D_o, D_n and D_t indicate the initial ball diameter, maximum ball span normal and tangential 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 (both in normal and tangential deformation) was selected from that ball image with have a maximum ball deformation (*see* Fig. 2(c)).

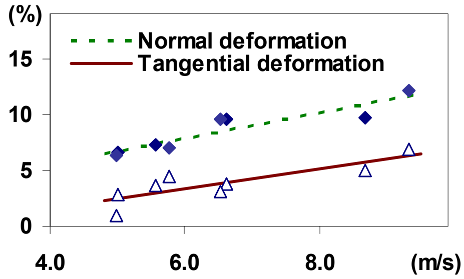

Figure 3. Maximum ball deformation ratio (%) as a function of inbound ball velocity (m/s) for both normal and tangential deformation

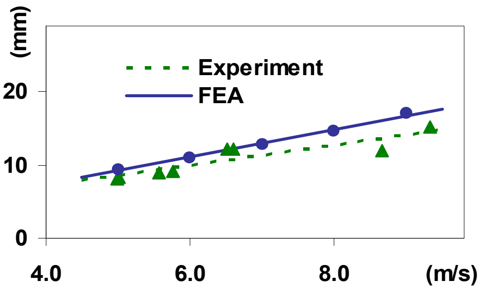

Figure 4: Maximum normal ball deformation (mm) for both experimental and FEA results as a function of inbound ball velocity (m/s)

Figure 3 shows the maximum deformation ratios as a function of the inbound velocity, where the dotted line and solid line were determined using the least squares method. Here the maximum ball deformation for both normal and tangential direction increases with the ball velocity with the normal deformation larger than tangential deformation. The average ratio between tangential to normal deformations from experimental results is about 0.4. Similar results were also found in FEA simulation where the maximum normal ball deformation increases with inbound ball velocity (Fig. 4). Since the study was unable to determine the tangential displacement from simulation, thus the maximum tangential deformation was not measured from this FEA simulation.

Contact time and coefficient of restitution (COR)

In the experimental method, the contact time between the ball and the flat surface was estimated from the first and final contact images (*see* Fig. 2). If an image having a small deformation at the both first and final contact then the images were corrected by using an image just before and after the contact. Figure 5 shows the contact time of the ball as a function of inbound ball velocity for both experimental and FEA simulation results. Both methods show the same trend where the contact time increasing with the inbound velocity of the ball. However the contact time from FEA simulation results are less than the experimental results especially at low inbound velocity.

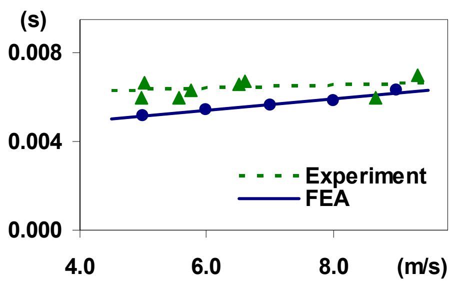

Figure 5. Contact time (s) of the ball impact as a function of inbound ball velocity (m/s)

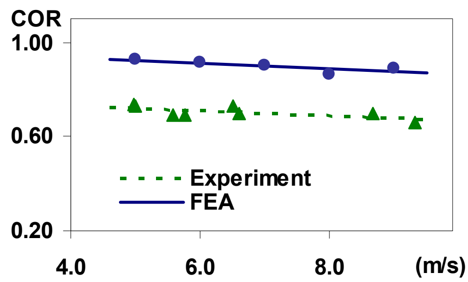

Figure 6. Coefficient of restitution (COR) of the ball as a function of inbound velocity (m/s)

The coefficient of restitution (COR) of the ball was calculated as the ratios of the velocity after the ball impact to that the velocity befor e the ball impact (Farkas & Ramsier, 2006). From both experiment and simulation results the value of COR is decreases with increasing inbound velocity of the ball (see Fig. 6). The result is opposite to that of maximum normal ball deformation against the inbound ball velocity. Thus, the reduction of the COR value can be ascribe to the energy loss due to the ball deformation during impact. This found to be similar with a study on golf ball impact (Arakawa *et al.*, 2008). The impact of the ball from FEA simulation seems to be more elastic compared to the actual experiment. Thus the FE model of the takraw ball needs to be improved by considering a non-linear deformation.

Impact force during contact time

Figure 7 shows the impact forces as a function of time for a different height. Both experimental and FEA simulation results illustrates that as the impact force increased in the early stages of the impact and then decreased in the later stages. However the results for FEA simulation described inconsistency decreased at the later stages as the height of free drop (i.e. at the inbound velocity of 6.53 m/s) is increased. Thus further improvement need to modify on the current FE model in order to adapt at higher velocity of the ball during a normal impact.

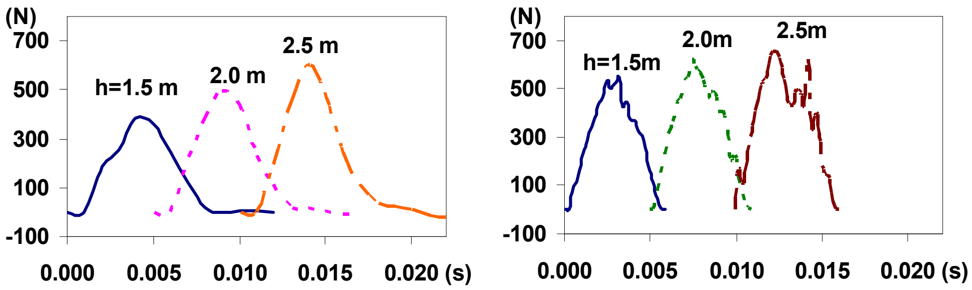

Figure 7. Contact force history (N) determined from experimental results (at left side) and FEA results (at right side)

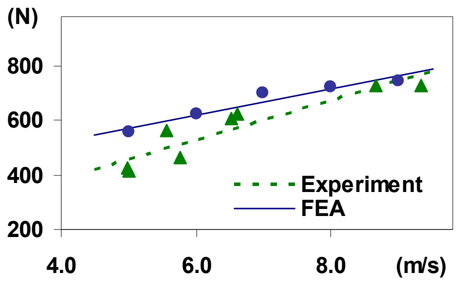

Figure 8. Maximum impact force (N) as a function of inbound ball velocity (m/s)

Figure 8 shows the comparison between experimental and FEA simulation results for the maximum impact force as a function of inbound velocity. Here both results showed the increment of maximum impact loads with increasing inbound ball velocities. The results also indicated that the difference between experimental and FEA methods was decreased with increasing the ball velocities.

5 Conclusion

In this study two methods were employed to measure the dynamic behavior and mechanical properties of takraw balls. The first method uses high speed video camera together with a force plate and the second method is the used of finite element analysis (FEA).All the impact force, ball deformation, contact time, and coefficient of restitution (COR) were determined as a function of inbound ball velocities. Both methods have provided evidence that the dynamic behavior of the takraw ball were influenced by the effects of ball velocities before impact.

The FE model of the takraw ball with linear elastic model of material properties were constructed by varying the elasticity modulus and Poisson's ratios. The difference between the experimental and FEA simulation for the maximum ball deformation and impact force was 12% and 15%, respectively. The FEA solution of the ball model was found to be reasonable close with the experimental results. However 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 before the impact.

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