Acta Technica *62* No. 3A/2017, 303–312

Hardness measurement and impact test for table tennis ball

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Abstract. A new hardness measurement method for table tennis was put up based on theoretical analysis on hardness measurement mechanism for table tennis ball. First, two hardness measurement methods for table tennis were put forwarded based on traditional measurement methods, with which table tennis ball were classified on its hardness. Tests results showed that the measurement methods were more effective than the original one. Then, impact test device for table tennis ball were designed to study relation of hardness of table tennis ball and its speed when hitting at different positions with the same force. Test results showed that these two measurement methods were practical and reasonable. The maximum rebound speed of table tennis ball was different when the ball was hit at different positions with the same force. Three-star table tennis ball was more suitable for international games because its hardness was distributed more evenly and the speed was almost the same when hit at different positions.

Key words. Table tennis ball, hardness measurement, impact, deformation.

1. Introduction

Table tennis is the national sport of China, thus there is a growing demand for table tennis every year. Complex steps and long period was needed to produce a table tennis ball [1]. With the increasing demand of table tennis ball, original hardness measurement method for table tennis could not meet the requirement of modern industrial manufacturing. Fortunately, hardness measurement for table tennis ball was greatly promoted by the improved modern measurement instrument for table tennis ball, especially high sensitive electronic material tester [2]. Thus, improving hardness measurement efficiency for table tennis ball was of practical significance for improving measurement efficiency of table tennis ball. Based on hardness measurement mechanism for table tennis, a new method was put forward to provide theoretical basis for design hardness measurement instrument with high efficiency and accuracy.

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2. Literature review

Nowadays, most studies were about metal hardness and devices for measuring it while there were few studies about hardness measurement method for table tennis. Before studying mechanism for measuring hardness of table tennis ball, mechanism of table tennis ball should be studied. Table tennis ball was similar to spherical shell. And studies about spherical shell were mainly focused on quasi-static, large deformation and back-buckling and elastic deformation and bounce back of thin-wall spherical shell after impact [3]. D. P. Updike [4] was the first one to theoretically research spherical shell. Spherical shell deformation in quasi-static compression process was regarded as complete elastic deformation and ideal plastic deformation respectively. When spherical shell was under concentrated load, relation of force and load displacement was inferred theoretically and experimentally. Instability and energy change of spherical shell under dynamic impact was studied by M. Shariati et al. [5], whose theoretically study was essential for the following studies.

It was aimed to find out a new hardness measurement method for table tennis in order to provide a theoretical basis and technical parameters to reasonable classify table tennis according to its hardness. With the new practical hardness measurement method for table tennis, measurement efficiency was improved and the produced table tennis was standardized. This new method played an important role in strengthening companies' competitiveness in domestic and international markets. Thus, study on hardness measurement for table tennis ball and its speed after impact provided the crucial theoretical foundation and technical parameters for increasing efficiency of production line.

3. Research method

Traditionally, hardness of table tennis was measured by its deformation. However, with the increasing demand for table tennis ball, the traditional method was no longer suitable for modern production line. A new platform for hardness measurement method for table tennis ball was provided by modern measurement instrument. Using this method, 15 seconds should be remained before reading. In practical table tennis, table tennis ball was hit instantaneous, thus there was no science basis for waiting 15 seconds before reading. Besides, production efficiency would be lowered with this method. Thus, a new hardness measurement method for table tennis was put forward, with which no remaining time was needed and deformation was measured directly under limit load. Principle for measuring was that measuring hardness of table tennis ball with the bearing load when deformation was the same. It meant that impose load to table tennis ball gradually and stop loading at a certain degree of deformation. Therefore, hardness of table tennis ball was classified on the load value.

Electronic material tester of LRXPLUS 5KN was used to measure hardness of table tennis ball. Double Happiness table tennis ball of the same batch of one-, two- and three-star were chosen to be studied. And for each level, 70 table tennis balls were chosen and numbered. Before experiment, all table tennis balls should be

put under temperature of 20–25 °C and humidity of 50–60 % for 4 days. One of the important parameters for measuring hardness of table tennis ball was bearing capacity [6]. For identify the bearing capacity, there were two methods- experimentation (combining static load experiment with measurement technique) and theoretical calculation (specification-based approach and balance method). The bearing load of table tennis was identified by experiment, which can be used to identify its limit load before deforming. Both the limit load and the ultimate displacement measured by new method can be inferred by the limit load. Ultimate load of those table tennis balls studied (all table tennis ball of one-, two- and three-stars) was 80 N and load-displacement curve before deformation was almost in linear relation. In order to increase hardness measurement efficiency, 50 N, 60 N and 70 N were taken as the limit loads for experiments respectively. Thus, limit load of the new method was identified by comparison. Structure of the hardness measurement device is shown in Fig. 1.

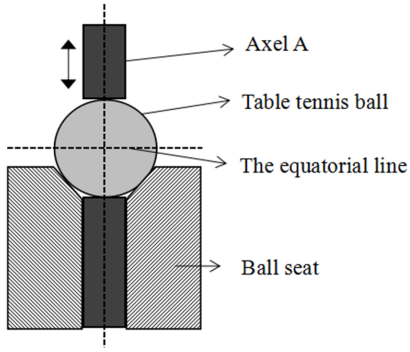

Fig. 1. Hardness measurement device for table tennis ball

Specifically, there are two testing schemes which were shown as follows:

Scheme 1: Measuring deformation of table tennis ball with limit load.

Step 1: First, No. 1 table tennis ball of one-star was put on ball seat and its junction line was kept parallel to horizontal line of ball seat. Load axis A was down moving with speed of 12 mm/min. When the load of table tennis ball reached 50 N, put load axis A back to the initial position and record its load-deformation curve graph. Then, table tennis ball was rotated by 180 degrees and measured with the same method to record its load-deformation curve graph.

Step 2: Table tennis balls of one-star from No. 1 to No. 10 were put on the ball seat and experimented with above method, respectively. Curve graph of deformation and load-deformation was recorded.

Step 3: Change those table tennis balls into one-and two-star respectively to repeat Step 1 and Step 2.

Step 4: Take limit load as 60 N, 70 N and 80 N respectively and repeat Step 1–Step 3.

Scheme 2: Set ultimate deformation to measure corresponding loading value Measurement principle: impose load to table tennis ball gradually and stop it when

the deformation reached a certain degree. Hardness of table tennis ball was classified with the loading value. Measurement steps were as follows:

Step 1: No. 51 table tennis ball of one-star was put on ball seat and its junction was kept parallel to horizontal line of ball seat. Down move axle A with constant speed of 12 mm/min and stop it when table tennis ball was caved into 0.8 mm. And record load-deformation curve graph and the relevant data.

Step 2: Ten other table tennis balls of one-star were changed into repeat step 1 and then, record relevant data.

Step 3: Repeat above steps on table tennis ball of two- and three-star and record relevant data.

Step 4: Set limit-deformation as 1.0 mm and 1.2 mm and repeat above steps.

3.1. Impact test

For explaining hit by luck, it was necessary to study speed of table tennis ball when it was hit at different positions, which study was also important for further table tennis manufacturing and performance measurement. Experiment for hardness measurement and speed of table tennis ball after hit was studied.

Structure of hardness measurement was shown in Fig. 1 that it was made up of electronic material tester and self-made ball seat. Nine Double Happiness table tennis ball of one, two- and three-star of the same batch were chosen and numbered. Mark 9 points on those table tennis balls in the direction of longitude, including 0 degree, 25 degrees, 45 degrees, 70 degrees, 90 degrees, 115 degrees, 135 degrees, 160 degrees and 180 degrees. First, No. 1 table tennis ball of one-star was put on ball seat and mark of 0 degree was put right below axis A. Down move axis A with speed of 12 mm/min and stop it and remain 15 seconds when table tennis ball was loaded 50 N. Then, move axis A back to the original position. All those 9 marked points have to be studied with the above method and all experimental data was recorded.

Impact tester device was mainly made up of impact test device for table tennis (built with 30×30 proximate matter), HG-100K high-speed camera and signal analysis system. Table tennis ball was put on the horizontal ball seat of impact test device and self-made scale mark caliper was stick on the appropriate position of proximate matter. Impact tests for one-, two- and three-star table tennis balls were made on marked points of 0 degree, 45 degrees, 90 degrees, 135 degrees and 180 degrees and each experiment was repeated for 3 times. In the same time, process of table tennis ball ascending to the highest point was recorded by medium-high speed camera with which signal was transmitted to DASP intelligent data acquisition and analysis system.

4. Results and analysis

4.1. Hardness measurement result and analysis

Curve graph of elongation-loading value was outputted by electronic material tester. However, when elongation started changing, load value was not 0. In order

to reflect relation of deformation and loading, Matlab software was used to fitting data outputted by tester again.

- Scheme 1:

  When limit load was 50 N, the curve graph of deformation and load is shown in Fig. 2. Curves 1–5 are the experimental values randomly selected and curve 6 is the mean value of those 5 curves. It can be seen from Fig. 2 that there wi a linear relation between deformation and load when the limit load is 50 N. In this situation, deformation of table tennis ball represents an elastic deformation, under which table tennis ball could resume its original shape, thus table tennis ball can be used normally.

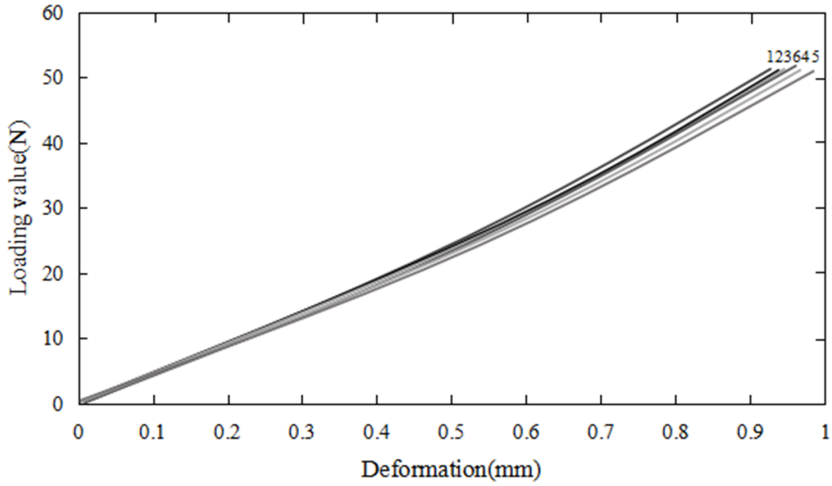

Fig. 2. Curve graph of elongation-loading value when limit load was 50 N (one-star table tennis ball, loading speed 12 mm/min, temperature 24 °C)

The maximum deformations of table tennis balls of one-, two- and three-star under limit load of 50 N are depicted in Fig. 3. And it can be seen from this figure that under the conditions of same loading speed and temperature and no remaining time during the process, different deformation is shown by table tennis balls of different stars. Besides, deformation of table tennis ball of different levels satisfy the relation that three-star deformation is smaller than two-star deformation and this is smaller than one-star deformation, which basically conforms to classification of table tennis ball of different number of stars.

Experiments on those table tennis balls of one-, two- and three-star were made on 4 different limit loads, respectively. When limit load was 80 N, there was squash deformation for all table tennis ball, thus those measurement data was not included in Table 1. The other data are shown in Table 1.

It can be seen from Table 1 that under the same loading, there was relation of three-star deformation $<$ two-star deformation $<$ one-star deformation. It

can be known form standard deviation that hardness value of three-star table tennis was more concentrated than that of two-and one-star table tennis ball, which meant that three-star table tennis ball was more suitable for major match because of more stable quality.

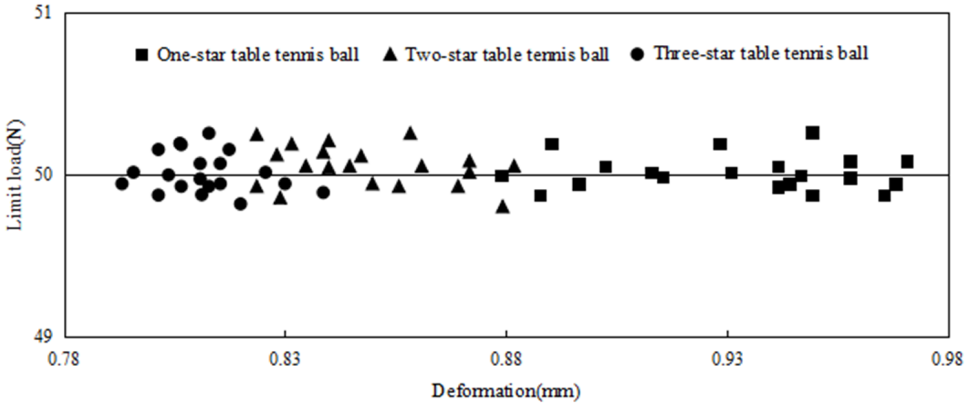

Fig. 3. Distribution of the maximum deformation of table tennis ball of different level under loading of 50 N

Table 1. Detection accuracy evaluation

Limit load	50 N			60 N			70 N		
	Times	Mean value (mm)	Standard deviation	Times	Mean value (mm)	Standard deviation	Times	Mean value (mm)	Standard deviation
One star ball	20	0.922	0.0262	20	1.169	0.0378	20	1.231	0.0282
Two star ball	20	0.843	0.0238	20	0.992	0.0367	20	1.122	0.0265
Three star ball	20	0.828	0.0157	20	0.978	0.0117	20	1.085	0.0379

- Scheme 2:

  When deformation was 1.2 mm, curve graph of deformation and loading of table tennis ball of one-, two- and three-star is shown in Fig. 4 and the corresponding loading is shown in Table 2.

  It can be seen from Fig. 4 and Table 2 that when deformation was less than 1.2 mm, loading value of table tennis ball was increasing with the increasing deformation and there was a linear relation for fitting curve of loading-deformation. Under the same ultimate deformation, there was a relation of

three-star deformation > two-star deformation > one-star deformation, which means that quality of three-star table tennis ball is more stable.

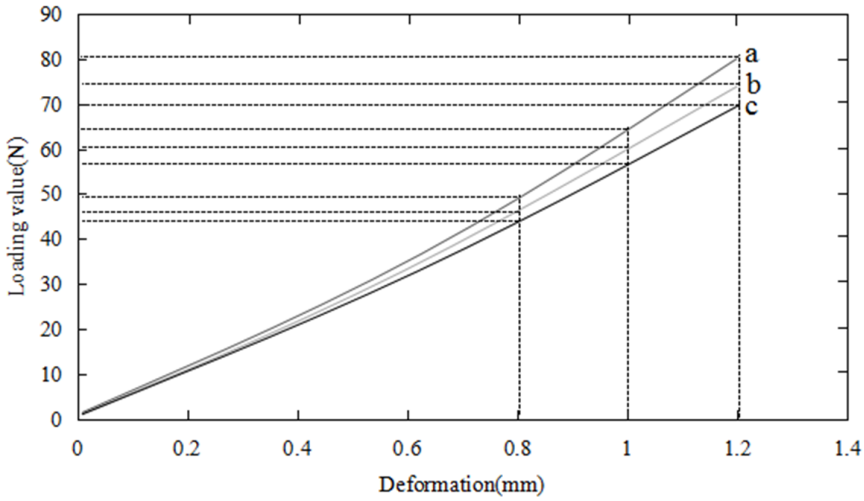

Fig. 4. Curve graph of deformation and loading when limit deformation of table tennis ball was 1.2 mm (a: one-star table tennis ball, b: two-star table tennis ball, c: three-star table tennis ball)

Table 2. Maximum load of table tennis ball of all three stars under the same deformation

Limit load	0.8 mm			1.0 mm			1.2 mm		
	Times	Mean value (mm)	Standard deviation	Times	Mean value (mm)	Standard deviation	Times	Mean value (mm)	Standard deviation
One star ball	20	43.68	2.754	20	55.15	4.586	20	48.72	5.712
Two star ball	20	46.05	3.562	20	60.18	3.068	20	64.09	6.927
Three star ball	20	49.13	0.931	20	74.62	1.788	20	79.11	4.138

To sum up, table tennis ball can be classified with these two measurement methods put forward.

4.2. Result and analysis of impact test

Data of those 9 tests for table tennis ball of one-, two- and three-star was outputted. Deformation of table tennis ball under load was calculated. Then, the mean values of those 9 points were calculated. Matlab software was used to fit tests results of table tennis balls for 4 times. Curve graph of deformation and position angle of half of the table tennis balls was obtained and is shown in Fig. 5.

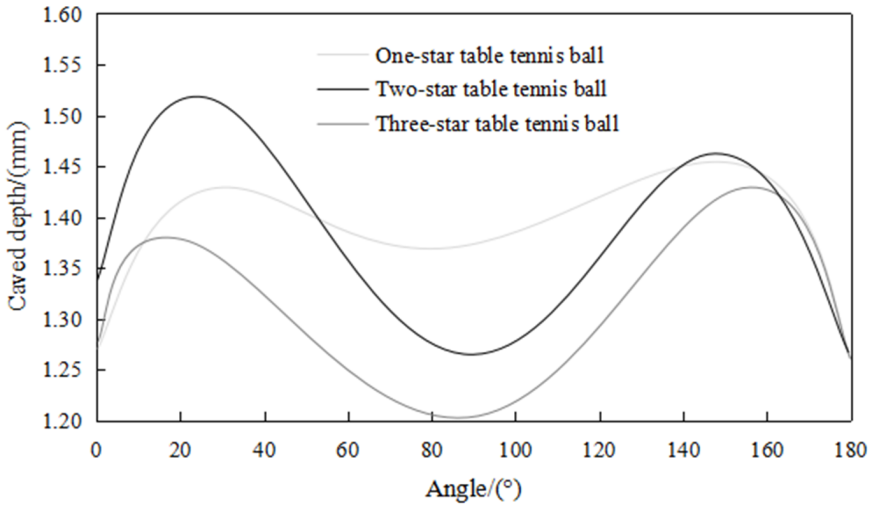

Fig. 5. Curve graph of deformation changing with position of table tennis ball

It can be seen from Fig. 5 that hardness of table tennis ball at the junction was larger than that of other monolayer around it. Junction line was a ring-like strengthening rib of table tennis ball. In the thin-shell structure, ring-like strengthening rib was able to stabilize the structure, improve loading bearing capacity of axial stress and lower the rate of squash.

High-speed camera was used to record process of table tennis ball moving up to the highest point. Image that contained complete picture of table tennis ball was selected. Gaussian Mixture Model [7] was used to identify position of table tennis, thus binary image was obtained. In this situation, dash area in image was remained, which was removed according to differences of color of table tennis ball and the dash area. A circular area in image was extracted by Hough Transform whose center was identified by function provided by OpenCV, thus center of table tennis ball was calculated. After image processing, the highest point of each experiment result was selected. Mean value of those highest points was computed. Curve graph of the highest point changing with angle was obtained by data fitting, which was shown as Fig. 6.

It can be seen from Fig. 6 that the given table tennis ball was hit by the same force in the same direction, table tennis ball rose to its peak when hit at 90 degree mark and rose to its lowest point when hit at the junction. The closer to 90 degree position, the higher position of table tennis ball rose to.

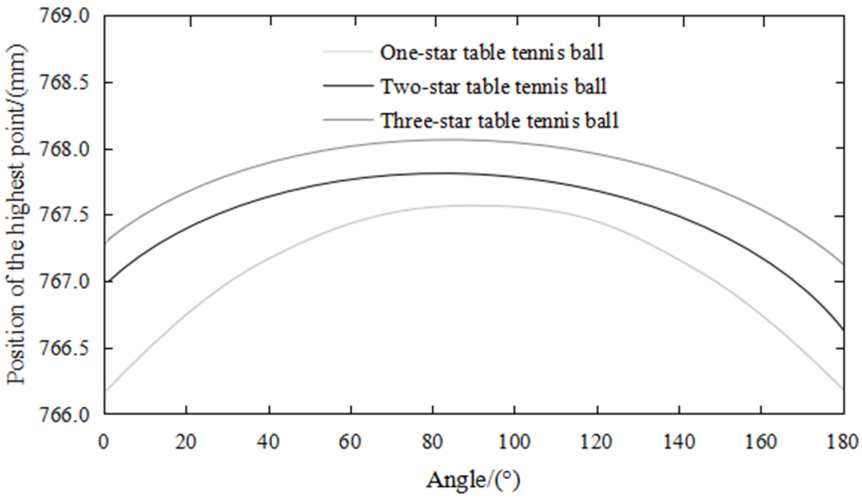

Fig. 6. Curve graph of the highest point changing with angle

In conclusion, speed of table tennis ball was changing regularly to a certain degree when it was hit by the same force because hardness of table tennis ball was changing with angle. However, changing rule of speed and its hardness was not completely the same. Hardness at junction line was relatively larger than that of other areas. However, when table tennis was hit at junction line, the speed after hit was the slowest. It can be inferred from the results that the larger hitting force, the more energy lost and the larger difference between initial speeds of table tennis balls because of uneven hardness of table tennis ball. Besides, one of the important reasons for hitting by luck was that contact area of table tennis ball and racket was increased because table tennis ball rotation was influenced by the uneven hardness.

5. Conclusion

First, two hardness measurement methods for table tennis ball was put forwarded, which was verified effective by a serial of experimentations and analysis of Matlab software. Then, impact test was designed to study relation of hardness of table tennis ball and the speed after hitting when table tennis ball was hit at different place with the same force. With the methods put forwarded, it can not only classify table tennis but also provide an explanation for hit by luck during match, which provided a reference standard for future table tennis production.

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Received May 7, 2017