

Coefficient of Restitution of a Takraw Ball

Passawit Jongsuebchoke and Kris Pornsirikul

*International School Bangkok
39/7 Samakee Rd, Pakkret,
Nonthaburi, 11120, Thailand
Email: krispornsirikul@gmail.com*

Abstract

Takraw is a popular sport in Southeast Asia that is akin to “Foot Volleyball”. It is played by two teams kicking a woven rattan or polymer ball over a net. The coefficient of restitution of a polymer takraw ball impacting the floor at a velocity of 5 ms^{-1} was measured for ball temperatures ranging between 1 and 59°C . The coefficient of restitution was determined for impact velocities between 4.7 ms^{-1} and 19.3 ms^{-1} using a 240fps camera. It was shown that reductions in the COR of the ball with increasing temperature and impact velocity can be represented to a good approximation by linear regression lines over the range of temperatures and energies likely to be encountered in actual play.

Keywords: Takraw ball, coefficient of restitution, impact velocity, temperature

1. INTRODUCTION

The objective of Takraw, figure 1, is to score points by returning a woven ball repeatedly over a net using the feet, knees, chest, and head. Takraw balls were once woven from rattan as shown in figure 2 (left), but modern competition balls are made from synthetic polymer (figure 2, right).

Since takraw is played in various temperatures, and the ball is kicked with a wide range of foot impact speeds for different shots, the effects of temperature and impact velocity on how well the ball bounces, which can be quantified by the

coefficient of restitution, is important. This paper aims to empirically establish the effect of temperature and impact velocity on the coefficient of restitution.

The coefficient of restitution (COR) for a two-body collision is defined as the ratio of the relative velocity after impact over the relative velocity before impact.³ For the case of a ball impacting the floor, the COR can be expressed as:

$$COR = \frac{v}{u}, \quad (1)$$

where v and u represent the final and initial velocities respectively.



Figure 1. A game of competitive Takraw.¹



Figure 2. Traditional takraw ball made of rattan² (left) and the MT 201 Takraw ball used in this experiment (right).

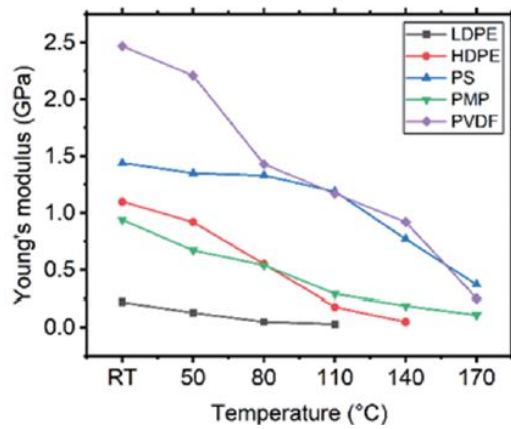


Figure 3. Young's Modulus as a function of the polymers LDPE, HDPE, PS, PMP, and PVDF.⁵

When a takraw ball bounces, it loses energy when the ball is deformed and returns to its original shape.⁴ Since the ball is made of woven fibers, energy will also be lost through friction as the fibers rub across each other during the ball's deformation.

Young's Modulus of polymers decreases with increasing temperature,⁵ as shown in figure 3, which leads to more deformation at higher temperatures. Therefore, the COR is expected to decrease with increasing temperature as the polymer softens.

The temperature of a table tennis ball has been shown to have a negative linear relationship with COR (figure 4).⁶ Since table tennis balls and takraw balls are both made of polymer, albeit different types of polymers, the trend is expected to be the same for the two balls.

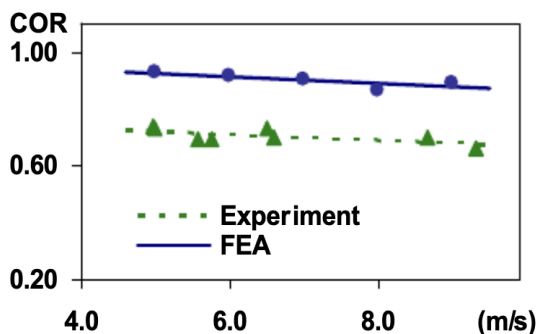


Figure 5. Ahmad et al results of the effect of impact velocity on COR of a Takraw ball. The experimental results (green) and the finite element analysis (blue) are shown.

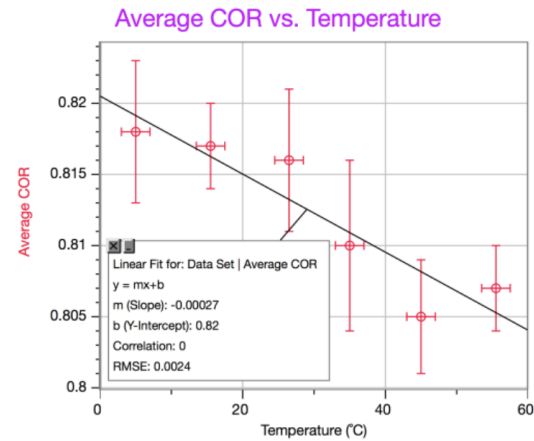


Figure 4. Temperature and COR of a table tennis ball.⁶

Ahmad et al showed that the relationship between impact velocity of a takraw ball and COR follows a negative linear regression (figure 5).⁷ Ahmad et al's study is limited as speeds greater than 10 ms^{-1} were not tested. With elite takraw players serving with ball speeds up to 20 ms^{-1} ,⁸ this study will aim to both confirm Ahmad's results and improve the applicability of the model for the full range of in-game velocities.

II. METHODS

To determine the effect of temperature on COR, an MT 201 takraw ball of diameter 14.3 cm was placed into containers with temperatures ranging from 1°C to 59°C for 45 minutes until the temperature stabilized. The ball was then removed and quickly released from a height of $120 \pm 3 \text{ cm}$ under a Vernier motion detector recording at 40 samples per second, as shown in figure 6. Five trials were done for each temperature.

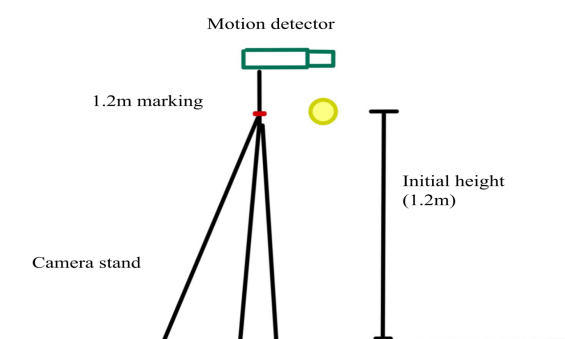


Figure 6. Setup for temperature vs. COR experiment.

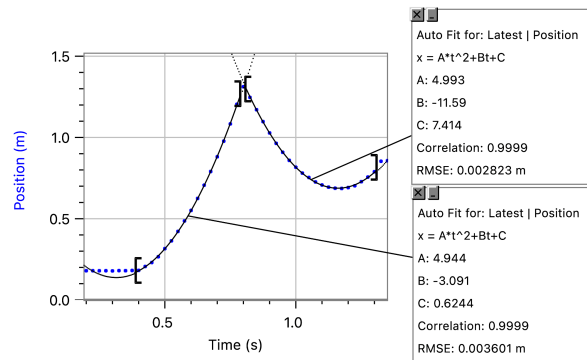


Figure 7. The derivative function of both parabolas at the moment of impact was calculated.

The impact and bounce velocities were calculated by fitting two parabolas to the position of the ball, one before the bounce and one after the bounce, as shown in figure 7. The impact velocity is the derivative of the first parabola at the instant before the bounce. Similarly, the final velocity is the derivative of the second parabola at the instant after the bounce. The velocities are then used to calculate COR.

To determine the effect of impact velocity on COR, the ball was thrown vertically into the floor at a range of velocities, as shown in figure 8. An iPhone 14 Pro recorded the ball's impact on the floor at 240 frames per second and ball position was tracked using LoggerPro video analysis (figure 9). Impact and final velocity were calculated from the subsequent position time graph by fitting a linear fit to the position of the ball for the seven frames before and after impact (figure 10).

Only trials with impact orientations within 5° of perpendicular were included. A total of 48 different impact velocities ranging from 4.1ms^{-1} to 19.3ms^{-1} were recorded.

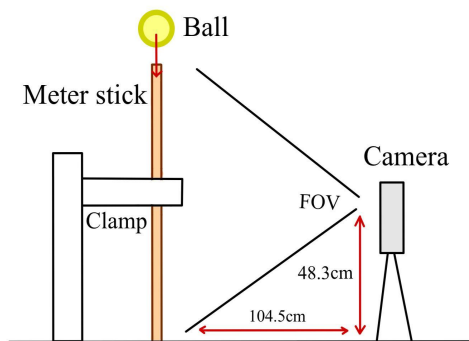


Figure 8. The setup of the experiment to measure COR as a function of impact velocity.

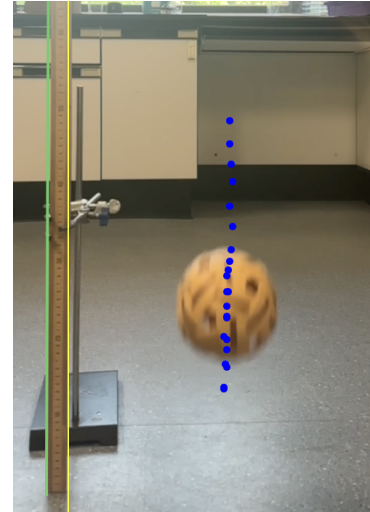


Figure 9. Logger pro frame-by-frame video analysis, dots depict the top of the ball in each frame.

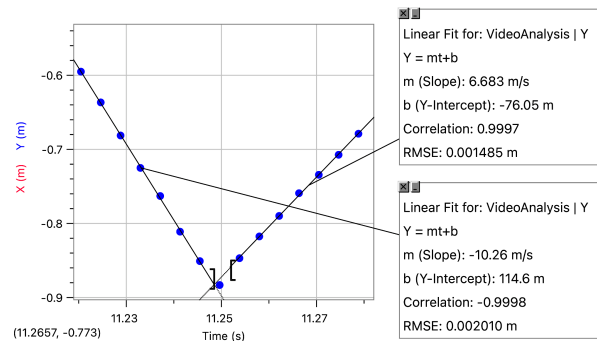


Figure 10. Position time graph resulting from the ball displacement in Figure 9.

III. RESULTS AND DISCUSSION

The relationship between temperature and COR of the takraw ball is shown in Figure 11. It can be modeled by the following equation:

$$COR = (-1.1 \pm 0.1\text{mC}^{-1})T + (0.699 \pm 0.004) \quad (2)$$

As temperature increases by 1°C , the COR decreases linearly by 0.0011. As predicted, the decrease in Young's Modulus of the polymer ball with increasing temperature caused an increase in energy loss during impact, and hence a decrease in COR.

As expected, the decreasing COR with increasing temperature of the takraw ball also matches the behavior of the table tennis ball (Figure 3). However, the rate of COR decrease of the takraw ball (-0.0011) is four times larger than that of the

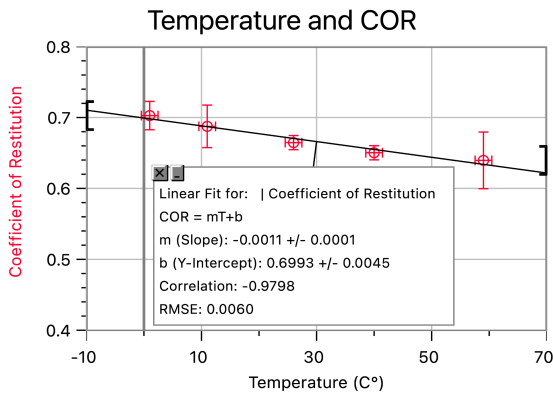


Figure 11. The negative linear relationship between average COR and temperature.

table tennis ball (-0.00027). This means that the takraw ball has a much higher rate of increase in energy loss with increasing temperature than the table tennis ball. The takraw ball's material and table tennis ball's material have similar Young's Moduli, 0.3-3 GPa and 1.5-2.6 GPa, respectively.⁹ Since both are also polymers, they are expected have a similar rate of decrease in Young's Modulus, as shown in Figure 2. This suggests that the reason for the greater rate of energy loss in the takraw ball is likely its woven structure. As the ball deforms, the ball fibers likely slide across each other, causing energy loss due to friction.

The model represented by equation 2 is valid for temperatures ranging from 1°C to 59°C. Further temperatures could be tested beyond this for interest, but the practical value of such testing is limited.

The relationship between impact velocity and COR of a takraw ball is shown in figure 12. It can be modeled by the following equation:

$$COR = (-0.012 \pm 0.005 m^{-1}s)u + (0.78 \pm 0.06) \quad (4)$$

As impact velocity increases by 1 ms⁻¹, COR decreases linearly by 0.012.

Figure 12 compares our results with those of Ahmad et al. The experimental results found by Ahmad are within the uncertainty of our results, providing confidence in the proposed model and extending the range of velocities to which the model can be applied.

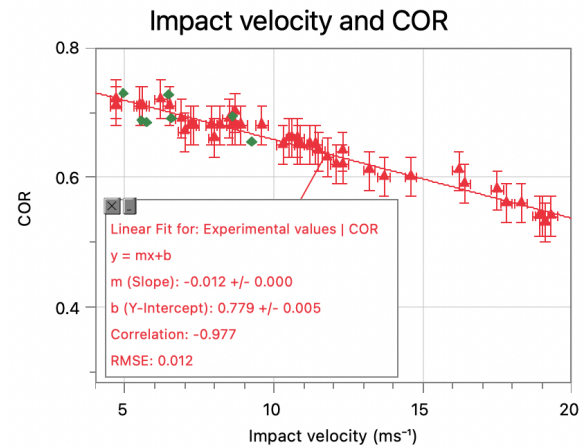


Figure 12. The negative linear trend between the initial velocity of the takraw ball and COR (Red). Results from ahmad et al (green).

The model represented by equation 4 is valid for velocities ranging from 4.1 ms⁻¹ to 19.3 ms⁻¹. Further velocities could be tested beyond this for interest, but the practical applications of such testing are limited.

IV. CONCLUSION

The empirical model for the relationship between temperature and coefficient of restitution of a MT 201 takraw ball showed a negative linear relationship for temperatures ranging from 1 to 59°C. A negative linear relationship was also shown between impact velocity and COR of the ball for velocities ranging from 4.1 to 19.3 ms⁻¹.

V. REFERENCES

1. Post, B. (2023, September 30). *Thai takraw teams soar to victory*. Bangkok Post. <https://www.bangkokpost.com/sports/2655041/thai-takraw-teams-soar-to-victory>
2. Service, I. E. L. (2003). *Takraw Ball*, Thailand Islington Education Library Service. <https://www.objectlessons.org/childhood-and-games-world/takraw-ball-thailand-/s82/a212/>
3. *Coefficients of Restitution*. (n.d.). <https://kvis.ac.th/userfiles/files/Coefficients%20of%20Restitution.pdf>

4. *Hysteresis for Rubber*. (n.d.). <https://www.kvis.ac.th/userfiles/files/Hysteresis%20for%20rubber.pdf>
5. *Park Systems*. (2024). Parksystems.com. <https://www.parksystems.com/en/learning-center/lc-detail.learning242>
6. Chang, Y. (2016). Temperature and Coefficient of Restitution of a Tennis Ball. *International Scholastic Journal of Science*, 10. (1) <https://isjos.org/index.php?paper=Temperature+and+Coefficient+of+Restitution+of+a+Table+Tennis+Ball>
7. Hamdan, N., Suwarganda, E., & Wilson, B. (n.d.). 30th Annual Conference of Biomechanics in Sports -Melbourne 2012 413 Nadzrin Hamdan. Factors correlated with sepak takraw serve speed.
8. Ahmad, N., Taha, Z., Ujihashi, S., & Tanaka, K. (2009). An experimental study of the impact of a sepak takraw ball on a flat surface.
9. *Overview of materials for Acrylonitrile Butadiene Styrene (ABS), Extruded*. (2024). Matweb.com. <https://www.matweb.com/search/DataSheet.aspx?MatGUID=3a8afcdac864d4b8f58d40570d2e5aa&ckck=1>