Influence of Drop Height on the Impact Characteristics of Futsal Ball Size Four

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Abstract. Futsal research on the ball characteristic has received little scientific attention. Recently modern football has been developed that afford excellent ball control and delivering. Difference constructions and sizes of ball deliver different characteristics of the ball. The purpose of this study is to examine Futsal ball size four deformations and coefficient of restitution (COR) during the impact. In this study, the Futsal ball was dropped vertically under three conditions. A subject performed five repetitive drops off the ball to impact a steel plate. The ball velocity was measured by SparkVue motion sensor attached on the top of the apparatus while the deformation was recorded using a high-speed video camera, that can up to 1,000 frames per second. From the experiment, the ball deformation and COR were measured. The results obtained showed the deformation and COR value vary with different heights for the same type of Futsal ball size four. It shows that the different heights of ball drops give different ball impact characteristics. It was found that the COR depended on the amount of the deformation of the ball.

1. Introduction
In many sports, ball properties are held to strict standards to maintain a high level of consistency and performance. The ball itself is a critical component in specific sports such as football, hockey, tennis, and volleyball where those games have to meet strict requirements of game safety. To achieve better performance and quality, the sports ball design and manufacturing required a test, such as an impact test to ensure that the sports ball meets the safety requirements. The deformation of the ball itself plays an essential role in the performance of the ball. The design and development of sports balls are significant activities to gain competitive advantages within the market. Regardless of the market interest, the researchers aim to improve sports performance and to reduce injuries [1].

A head injury in football accounted as the highest number of injuries compared to neck injuries. The football-related head injuries may occur in at least four ways; head contact with the ball (heading), contact with another player, contact with the ground and contact with a stationary object. Head risks of football player injuries are increased in goalkeepers. The goalkeeper is the position that has the most risk of the casualties among the players. The goalkeeper needs to be ready with the oncoming balls, which in the position most at risk for head injury. They are also exposed to the impact of the ball at the fastball kick by another player [2]. During the actual games, the footballer can kick
the ball with speed up to 130 km/hr. Deformation plays a vital role in understanding the impact characteristics. Ball deformation results from the abrupt deceleration connected with its impact against another body. This is evident from a reduction in the ball’s diameter perpendicular to the impact surface. Many studies, which are conducted shown that the deformation was increased as the velocity increase. When a ball is dropped to the ground, the potential energy from the fall is used to deform the ball, which deformation stores the energy gained from the fall. Once the velocity downward becomes zero relative to in energy contained in the deformation, the stored energy pushed the ground and launched the ball back up.

The previous studies have shown that the COR decreased as the ball speed increased, as it was affected by the object released height [3]. During the football impact, the ball will undergo a significant deformation. The coefficient of restitution depends on the amount of deformation of the foot and the ball at impact, which results in a perfect collision by the material properties of the colliding objects. The higher deformation causes increase forces and release of energy [4]. The coefficient of restitution depends on the mechanical properties of the ball, the shoe, the ankle and the foot upon contact. Therefore, the highest deformation by the foot gives a lower coefficient of restitution [5].

From the available literature, have shown that from the standard size football ball, the value of COR varies from the types of the experiment conducted. From the pendulum experiment, the COR was approximately 0.82. From the experiment, by conducting the human kicking motion, the COR is between from 0.50 to 0.65. Additionally, other studies of COR effects from shoes had been conducted. It was performed the toe kicks for the football boot. It recorded that, the COR is varied from 0.4 to 0.8 [6].

The characteristics of the Futsal ball were different from the standard ball, as it differs from other size and the bounce of the ball. The Futsal ball less bounce compares to standard ball up to 30%. The present study aimed to examine Futsal ball size four characteristic impacts between the effects of height and the rigid plate target with three different height of drop impact. High-frames images were recorded on the point of impact to capture the deformation of the Futsal ball during impact. The motion sensor was employed at the top of the apparatus to determine the height of the Futsal ball bounce. The COR and deformation were then calculated using the formula. The present study aimed to examine the effect of the height of the ball drop to the characteristics of a Futsal ball size four.

2. Equipment and Methods

Adidas® FIFA standard Futsal ball size four with diameter 320 mm and weight 420g were used for the experiment [7]. Markers were placed on the specific area of the ball to measure the same face of drop test of the ball. The impact was captured using Mark IV SONY camera with 1,000 frames per second recording speed. The recorded video of the impact was then analyzed using the ImageJ software, and the normal and tangential deformation was calculated using the equation (1) and equation (2). The impact drop apparatus was attached with the SparkVue motion sensor to capture the ball impact velocity, the velocity before and after impact.

The measurement of ball deformation is likely to influence players’ perception of ball hardness softness. Deformation influences the trajectory strike of the direction of the ball [8]. To analyze the maximum ball deformation quantitatively, the maximum normal ($d_n$) and tangential ($d_t$) deformation ratios were calculated using the equations below;

$$d_n = 100|D_n - D_0|/D_0$$  \hspace{1cm} (1)

$$D_t = 100|D_t - D_0|/D_0$$  \hspace{1cm} (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 experiment was performed using the apparatus as shown in figure 1. The drop impact apparatus was designed with the maximum height of 1,800 mm. The frames of the impact test were built from hollow steel. The base of the impact test was from a 1.5 mm thickness, steel plate. The dropped case was free dropped from three different heights, 1,500 mm, 1,000 mm, and 500 mm high onto a rigid planar surface under the earth’s gravitational effect [9].

The dropped case for each height was conducted until five repetitions. The value of COR is calculated based on the height drop and bounce of the impact on the rigid plate. The COR was calculated using the equation (3). The amount of energy lost is described as a ratio between the inbound velocity and the outbound velocity, commonly known as the coefficient of restitution (COR). In the elastic of an impact, the value of COR has described the ability of a body to return to its original shape once it has been deformed.

$$e = \frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\frac{1}{2}}$$

The equation (3) derived related to the height by using the energy principle, from the conservation of mechanical energy. A perfectly elastic impact will result in zero energy loss, COR = 1, while a perfectly plastic impact results in a zero rebound height, COR = 0, with the COR of sports balls generally somewhere in between. The more elastic ball, the longer it bounces [10].

![Figure 1: The experiment set-up apparatus.](image1)

![Figure 2: Schematic diagram.](image2)
3. **Result and Discussions**

A ball dropped vertically onto a surface experiences a vertical Impulsive Force; \( F \) is defined as the change in momentum per unit time. \( F \) is typically 100-1000 times larger than \( mg \), in which case the gravitational force can be neglected during the impact. The assumption for this study, the air friction was neglected, as the ball drop was under the earth’s gravitational effects.

The magnitude of acceleration is equal to gravitational, in the absence of air resistance. In this experiment, the Futsal ball size 4 undergoes a drop test to impact with a rigid steel target. The normal and tangential deformation for each height drop as shown in Figure 3 and Figure 4.

![Figure 3: Calculated normal deformation with a different drop height.](image1)

![Figure 4: Calculated tangential deformation with a different drop height.](image2)

From the calculated analysis (figure 3 and figure 4), 1,500 mm recorded the highest deformation value for both the standard and tangential deformation. It had shown that the deformation of the Futsal ball increases as the drop height increases which was also ascertained by other authors [11, 12, 13].

For the normal deformation, the highest deformation shown from 1500 mm, was 3.874 mm, while 1000mm, and 500mm recorded 3.010 mm and 2.065 mm respectively. Meanwhile, for the tangential deformation, from 1500 mm was recorded at 7.142 mm, while 1000mm and 500 mm recorded 4.026 mm and 3.278 mm respectively. From this test, it is shown that the Futsal ball size 4 undergoes more tangential deformation compared to normal deformation.
The ball drop was captured using a SONY camera which rates that up to 1,000 frames per second (Figure 5). The image of the ball drop was measured using the ImageJ software.

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From the COR graph analysis above (Figure 6), 500 mm height recorded the highest COR value 0.5448 while 1,000 mm and 1,500 mm recorded 0.4538 and 0.3812 respectively. Figure 6 shows a reduction in COR with increase drop height, which was also ascertained by other authors [14, 15, 16]. The value of the COR was between 0.3 to 0.5, which can be said as an inelastic collision, which some kinetic energy is dissipated after the impact. A summary of the ball deformation and COR are shown in table 1.

| Characteristics                  | 1500 mm | 1000 mm | 500 mm |
|----------------------------------|---------|---------|--------|
| Max ball normal deformation (mm) | 3.874   | 3.010   | 2.065  |
| Max ball tangential deformation (mm) | 7.142 | 4.026   | 3.278  |
| Coefficient of Restitution (COR) | 0.3812  | 0.4538  | 0.5448 |

The above studies can be summaries that, the Futsal ball size 4 had difference characteristic as a standard football ball types. From the results table 1, it is shown that both normal and tangential deformation increased as the drop height increased. Compared to COR, the COR increased as the drop height decreased. It summaries that the COR depends on the deformation of the ball. The higher ball deformation that causes the increased force and also some energy dissipated.
4. Conclusion and Recommendation
From the drop test experiment, the deformation and the COR of the Futsal ball vary by the drop height of the ball. A COR depends on the amount of the deformation of the ball itself. The higher deformation of the ball, the less COR value of the ball. It can be concluded that the reduction value of COR can be related to the energy loss due to the ball deformation during impact. For the further work recommendation, an experiment with larger sample size and different models and sizes of balls could be conducted in future to obtain precisely and statistically analyze results.

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