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Investigation of Finite Element Model of Futsal Ball and Simulation of its Impact Characteristics

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Investigation of Finite Element Model of Futsal Ball and Simulation of its Impact Characteristics

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Futsal is gradually becoming the world's favourite game. Due to increasing technological advancement and demand for performance, ball manufacturers have progressively been introducing new designs over the years. Enhanced performance is essential to make sports equipment as user-friendly as possible to avoid injuries. To date, there is much controversy on the effects of the severity of ball impact to the head. The attention is on the repetitive heading tactics used by younger generations. This study aims to investigate the Finite Element model of the sizefour futsal balland the impact between a ball and a rigid surface to predict the dynamic properties of the ball during impact. A drop test impact experiment involves the measurement of the Coefficientof Restitution (COR), deformation, and contact time. A video camera in high-speed mode and a motion sensor are employedto measure the characteristics during impact. The Solidworks software is employed for modelling and simulation of the drop test impact experiment. The COR values reduce as the drop height is increased,while deformation and contact time increase as the drop height increases. The report shows that energy losses during impact increases as the drop height increased, it was showed by the increasing deformation of the futsal ball in each drop height. The three types of materials used for comparison are butyl, latex, and natural rubber. From the simulation, butyl is the most suitable material for the development of the futsal ball, as butyl rubber showed the minimum stress (0.082 N/m^2) and deformation (10612 mm) for each drop height. Natural rubber showed the highest stress (193.851 N/m^2) and deformation (2.950 mm) for all drop cases.

Keywords: Finite Element Model, impact test, deformation, coefficient of restitution futsal ball.

Penyelidikan Model Unsur Terhingga Bola Futsal dan Simulasi Ciri Impaknya

ABSTRAK

Semenjak kebelakangan ini, sukan futsal telah menjadi terkenal di seluruh dunia. Kemajuan sukan futsal ini dipengaruhi oleh kemajuan teknologi, disebabkan oleh itu, untuk peningkatan prestasi pemain futsal, pengeluar bola perlu secara progresif memperkenalkan reka bentuk baru. Peningkatan dalam penambah baikan dalam pembangunan peralatan sukan, adalah penting untuk menjadikan peralatan tersebut mesra pengguna dan selamat untuk digunakan. Dengan kemajuan teknologi sekarang, teknik menanduk bola telah menjadi perhatian dalam permainan bola. Tekanan dari menanduk molah telah menjadi persoalan dari segi keselamatan jangkan panjang kepada pemain. Terutamanya, kesan penggunaan teknik menanduk bola yang berulang di kalangan pemain generasi muda. Kajian ini dijalankan, adalah untuk menyiasat dan meramal sifat dinamik model unsur terhingga saiz empat bola futsal apabila dilakuan ujian hentaman. Ujian hentaman bola futsal dengan permukaan tegal adalah untuk mengukur pekali pemulihan, ubah bentuk, dan masa penyentuhan. Kamera video dapat merakam kelajuan tinggi dan sensor digunakan untuk mengukur ciri semasa ujian hentakan. Perisian Solidworks digunakan untuk pemodelan dan simulasi ujian hentakan. Nilai pekali pemulihan mengurang apabila ketinggian pelepasan ujian hentakan meningkat. Sebaliknya, keputusan uban bentuk dan masa penyentuhan bola futsal pada permukaan tegal meningkat, apabila tahap ketinggian pelepasan bola meningkat. Daripada sifat tersebut, ini menunjukkan nilai kehilangan tenaga bertambah apabila ketinggian pelepasan bola bertambah. Untuk ujian perisian simulasi, tiga jenis getah utama yang biasa digunakan untuk membuat pundi bola adalah butil, lateks, dan getah asli. Keputusan dari ujian *simulasi, menunjukkan butil adalah bahan terbaik dan sesuai untuk pembuatan bola futsal. Dapatan ini dibuat, kerana getah butil menunjukkan tahap ketegasan semasa hentakan dan kecacatan ubah bentuk yang minimum untuk setiap ketinggian ujian. Secara kesimpulannya, daripada kajian ini, telah menunjukkan bahawa terdapat perbezaan yang ketara diantara sifat dinamik bola futsal dan perbezaan di antara jenis bahan kepada tahap ketinggian hentakan bola yang berbeza.*

Kata kunci: *Model Unsur Terhingga, ujian impak, ubah-bentuk, pekali pengembalian, bola futsal.*

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LIST OF ABBREVIATIONS

a_g	Gravitational acceleration (9.81 m/s^2)
COR	Coefficient of Restitution
D_n	Normal diameter
D_o	Origin diameter
D_t	Tangential diameter
F	Force
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Model
FIFA	Fédération Internationale de Football Association
mm	milimeter
h	Height
KE	Kinetic Energy
MTBI	Mild Traumatic Brain Injuries
PE	Potential Energy
R	Pierson’s Correlation

CHAPTER 1

INTRODUCTION

1.1 Chapter Overview

The first chapter covers the research into ball development, the objectives and limitations of this research. This chapter also covers the significance of this study to the futsal ball developments.

1.2 Research Background

Futsal is a universal sport in its own right and differs from football significantly in terms of the rules of the games and the strategic actions involved. Both futsal and football are similar, about them being high-intensity activities that are based not only on aerobic but the anaerobic capacity of the player. Technically, the potential of the futsal player is partially influenced by way of the smaller ball, which forces the gamers to precisely and precisely counters to manage the ball.

Typically, the comparison between the standard ball and the futsal ball focuses on the inside of the bladder. The standard ball's bladder is filled with air, whereas the futsal ball, uses microfiber. Other than that, the standard size for the futsal ball is size four, with the circumference measuring in between 62 - 64 centimeter and weighing 410 - 430 grams.

The bounce of the futsal ball is less than the standard ball of football. Agility is a very significant component of both football and futsal, and it represents a common characteristic, and these two sports are much related to agility performance. Basic motions of these sports include passing and shooting in the foot. Players commonly use the side foot kick, which is an essential skill that is perceived to be more precise during kicking (Castellanos et al., 2012).

Figure 1.1: Futsal games require the same agility as football games

Figure 1.1 shown the Futsal players perform as same as to the actual football field player. This agility will be the difference between the players and results in the different speed of the ball upon impact. The ball velocity depends on the pace of the foot as properly as the best of the ball. The higher pace of the foot earlier than contact gives the highest velocity of the ball (Milanovic et al., 2011).

During impact, a deformation will appear. The coefficient of restitution relies upon on the quality of deformation of the ball and the ball on impact, which consequences in the best collision of the cloth residences on the colliding objects. The higher deformation causes an increase in forces and releases of energy (Kellis & Katis, 2007).

Other than that, the coefficient of restitution relies upon on the mechanical properties of the ball, the shoe, the ankle and the foot upon contact. Therefore, the highest deformation of the foot outcomes in a lower coefficient of restitution (Andersen et al., 2008). In recent years, all manufacturing methods have improved significantly and supplied for the need of the sport are in high demand. Balls are now manufactured entirely from the consistent thickness of synthetic materials, in order to ensure excellent durability qualities. However, manufacturing inconsistencies, such as poor sphericity and ball out-of-balance, are common defects that can occur during soccer ball production. Uneven mass distribution of the ball is known as the possible cause of the unbalanced ball in inconsistent ball's flight performance.

The use of finite element modelling (FEM) to depict the behaviour of solid sports ball is well-known, due to the need for grasp between dynamic properties and overall ball performance via each producer and governing bodies. Many previous studies were focusing on the biomechanics of the football player and the football size five, but less on the futsal ball size four. With this in mind, the impact of this study is to assess and examine the latest impact characteristics of the futsal ball size four. Figure 1.2 shows the standard futsal ball size four used in the standard games.

Figure 1.2: The standard futsal ball size four that generally used in the games

1.3 Problem Statements

The rules and techniques from futsal games are not much different from football. Both games are contact games which function the purposeful use of the head for advancing the ball. Contact to the head for the duration of the games, both through tackling duels, where two gamers are competing for ball control or purposely heading the ball, has the viable to cause traumatic brain injury (Rodrigues et al., 2016). The research mentioned that head injuries are increasing from year to year, as do the types of injuries, including facial fractures, lacerations, and eyes injuries. Figure 1.3 shown the deformation of the ball during the impact with head.

Figure 1.3: Heading a ball during games

The materials used today to make Futsal balls are mostly the same as in 1880s. All Futsal ball are made from rubber inside and leather on the outside. In the past, research on sport balls usually concentrated on the football field, (Hong et al., 2015). The Futsal ball behaviour attracted much less attention to date. There is an increasing need in research and development for a theoretical Futsal ball model that can be incorporated in the analysis of the ball stress and deformations.

Furthermore, with the growing concern for sports injuries, a model would also be used to improve the understanding of impact mechanisms between the Futsal ball materials. This type of modeling would allow cost-effective simulations of a range of impact events required in the development of the futsal ball.

Recently, advanced computer aided engineering (CAE) techniques have been widely used in manufacturing sports equipment to enhance the quality of the sports equipment produced and also to reduce the development time and cost. This is a powerful tool that allows for the simulation of high speed impact events that occur over very short period of time.

1.4 Research Questions

i. Is there any difference in the ball properties between the different heights of the ball impacts?

ii. What are the effects of ball materials on difference drop height?

1.5 Research Objectives

This research was conducted to investigate the effects of futsal ball size four impact characteristics on the height of the ball release. The performance of drop impact test with the futsal ball size four in this research was verified with Finite Element Model. The aim of the research is to measure the deformation, coefficient of restitution (COR) and the contact time of three types of Futsal ball materials at three difference drop height.

The main objectives of this project are:

i. To conduct a standard drop test to determine the deformation, contact time and COR of Futsal ball size four.

ii. To modeling and simulation of Futsal ball size four to determine the stress and deformation by compare three types of materials, (Butyl, Natural and Latex rubber).

1.6 Significance of Study

This study was conducted to look into the finite element model of futsal ball size four that undergoes a standard drop test. The finding from this study might benefit ball manufacturers to enhance ball properties by using the technology that focuses primarily on the selection of futsal ball material. Other than that, it contributes to the researches that are looking into the application aspect the technology into futsal ball.

1.7 Limitations of Study

The delimitation of this study is:

i. The free fall test of futsal ball is on 0.5, 1.0 and 1.5 meter for 35 trials on each drop height.

The limitations of this study are:

i. The speed of the ball cannot be controlled due to the fact that the ball is released by hand, and no equipment is used to hang the ball.
ii. The impact simulation of the futsal ball using the Solidwork is on solid shapes, as it assumes the futsal ball is filled with microfiber inside the bladder.

1.8 Scope of Study

In recent study, modelling and simulation were used for comparing the actual characteristics of various balls. However, there less study on the characteristics of the futsal ball on different height. The subject of the experiment was a Futsal ball size four.

The scopes of the study are:

i. The analysis is by conducting a standard drop test at three different height 0.5, 1.0 and 1.5 meter.
ii. The material constant (Butyl, Latex and Natural Rubber) with actual standards of the futsal balls size four used for the simulations test (FIFA Standard Ball for Futsal).

1.9 Thesis Organisations

This thesis consists of five exciting chapters. Chapter 1 introduces the context for the project. Chapter 2 is a literature review that covers the impact behavior of balls bounce and the applications of the finite element method in applying to sports equipment. Chapter 3 presents the material and the methods of the experimenting to determine the impact behavior of futsal ball size four during bounces and also the process of developing a finite element method and simulation of their impact. Chapter 4 covers the results of the experiment and the simulations of the study. This chapter also includes an analysis of the result. Lastly, Chapter 5, the conclusion and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

This chapter reviews the applicable literature for the lookup, which includes the ball-surface effect on and the application of Finite Element Analysis (FEA) to the sport.

2.2 Futsal History

Futsal is a game that is played by five players that consist of four field players and one goalkeeper. The standard court for international games measures 40 × 20 meter, with 3 × 2 meter for the goal. The futsal games are sports played in a small arena, and it uses a ball size four, which produces fewer bounces compared to standard balls. The ball typically has a standard circumference of 62 - 64 centimeter, with a weight of 390 - 430 grams, and a bounce range of 55 - 65 centimeter on the first bounces. The games involve two equal periods of 25 minutes halves, with a maximum of 15 minutes for half-time, compared to football's equal periods of 45 minutes halves.

Figure 2.1 show the Futsal game played by a child on the streets of Brazil. Most football player started their career at the Futsal courts, refined their moves and extended the acquired skills into the pitches.

Figure 2.1: Futsal game played by a child on the streets of Brazil

Initially, the futsal games started as a small-sided game on the street of Sao Paulo, Brazil. After that, the game quickly spread throughout South America is known as 'Futbol de Salao'. This was how futsal got its start.

According to a recent article (Payne, 2007) shown that, many people in Brazil use futsal as a medium for children to develop their abilities from the ages five until fourteen. In 1982, FIFUSA (before its membership was integrated into FIFA in 1989) organized the first Futsal World Championship in Sao Paulo, Brazil. Brazil became a dominant force in the first three editions before Spain won the title in Guatemala in 2000. Today, Federation International de Football Association (FIFA) is the governing body that helps to promote the futsal games, to make it more accessible and also as a representative body to develop the games and its equipment throughout the world. The futsal ball was integrated into the FIFA Quality Concept 2001 in order to ensure the highest quality and consistency worldwide.

The history of futsal in Malaysia started in the end year 1990, but it is still not a favourite sport when compared to other sports such as badminton and football. However, by the middle of 2000, futsal became the favourite sport among the young because it is easier to play and does not need many players, compared to football' that required a field and many players. Futsal is also well-received, not only for men but also garnered an encouraging response from the women. Also, the response from the children and the elderly is very favourable compared to football. Figure 2.2 shows the logo of Malaysian Futsal National Team the organisation under the Football Association of Malaysia.

Figure 2.2: Malaysian Futsal National Team under the Football Association of Malaysia

2.3 Development in Ball Materials

The British industrial revolution provided a catalyst for the development of the ball into its present day through the introduction of rubber to Malaya. It was revolutionary when the development of the balls allowed for the use of rubber materials to replace animal bladders. In the early years of the ball's history, a ball was built using the animal bladder and covered with leather for better shape retention.

The rubber vulcanised ball was designed and built by Charles Goodyear in era 80s. Charles was the first inventor for the first vulcanised rubber bladder by eliminating the dependence on pig bladder. The balls used rubber bladder to make sure that the ball remained tough and oval-shaped after the impact. In 1862, Lindon developed the first inflatable rubber ball bladder as shown in Figure 2.3 (Cox, 2017).

Figure 2.3: The first invention of the vulcanised rubber ball bladder

In 1863, the English Football Association introduced the new rules of the ball for the games. There was a problem during the first world cup soccer final, between Argentina and Uruguay. Both the teams do not agree to which ball to be used. During the games, they were decided in the first half to use the ball supplied by Argentina, while Uruguay supplied the second half. Then, the English Football Association came out with the rules, which it revised in 1972, that the ball ought to spherical with a circumference of 27 to 28 inches" (68.6 centimeter to 71.1 centimeter). That rule remains in FIFA laws to this day.

Figure 2.4: The ball in the early 1900s

The most important characteristic for the balls was retaining the shape after the kicking. The strength of the leather and skills of cutters and stitches played an essential role in these characteristics. By the 1900s, as shown in Figure 2.4, the ball was invented in bladders with stronger rubber means that balls could withstand the more massive pressure built. Most balls produced by that time used rubber bladders.

2.4 Impact Test

The impact test is a standard test which is usually used to determine the characteristics of the materials. Commonly, the impact test is widely used in research for the development of the sports equipment, such as rugby ball (Cross) and golf ball (Tanaka). An experimental impact test is used to determine the dynamic behavior of robust sports equipment. From the study manufacturer will produce the equipment close to the minimum legal size to save on material cost or manufacture near most legal size to fulfil patron demand.

The impact test is usually conducted in a standard drop test or by employing the equipment to simulate the actual action. The parameters that accumulate from the impact test, such as the characteristics of the equipment regarding the deformation, coefficient of restitution of the materials and also contacts time before and after the impact. Many researchers have used the drop test, impacting the hard surface of a sports ball to determine the dynamic behavior of sports balls.

Ahmad and Taha (2012), used the impact drop test to determine the dynamic behavior of the *sepak takraw* ball. Their research determine the impact force, contact time, the coefficient of restitution, and the deformation of the *sepak takraw* ball. Their experiments involve dropping the *sepak takraw* ball in a standard drop that impacts the surface. Other than that, some researchers conduct a drop test by employing the equipment to get a similar condition of the sport. Koizumi et al. (2014), produced a kick-robot to perform an impact test to get the same velocity in the repetition of the kicking test.

In their research, the researcher compared the impact of four types of soccer ball, such as the Cafusa, Jabulani, TeamGeist2 and Pelias. Figure 2.5 shows the apparatus that developed by Koizumi et al. (2014).

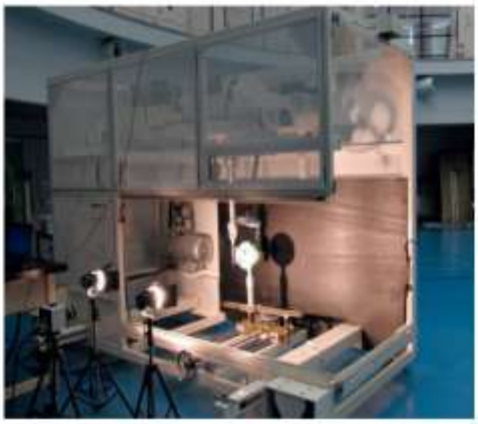


Figure 2.5: Kick-robot by Koizumi et al. (2014) was used to simulate real kick during a soccer game

Over the years, the makers of the ball gradually improved, with better consistency in shape and durability. Improvements on the ball regarding material properties are essential for the consistency of the game-play. Ball properties such as mass and pressure affect the severity of impact to the head as the ball is the source of the impact. The reduction in mass and pressure can limit the severity of a head effect (Shewchenko et al., 2005).

Together with the impact apparatus, other equipment is used to gather the dynamic characteristic of the sports ball. Frequently, a high-speed video camera is used to capture the deformation, while the sensor is attached for capturing a few data, such as velocity and contact time. High-speed cameras are the most common measurement method, besides the use of equipment such as laser light gates. By using the high-speed camera, the frame-rate and pixel resolution are imported criteria in the selection of the camera.

Zall et al. (2008) used a high-speed camera to record a drop impact test for the PCB. Zall research was focusing on the overall product reliability towards dropping.

Besides that, Tanaka et al. (2006), employed high-speed cameras to investigate the dynamic behavior of the golf ball. In their research, the golf ball was once fired from an air gun in a strain-free and non-rotational condition and collided with the top surface of the goal. This method was used to determine the general impact and oblique impact of the golf ball. Tanaka et al. (2010), also employed the high-speed camera again to determine the deformation of the golf balls by the difference in impact velocity. The specifications of the camera include 20000 fps and shutter speed of 1/100 000s. Figure 2.6 shown show the experiment set up by Tanaka on testing the golf ball impact.

Arakawa et al. (2009) determined the impact deformation of a golf ball by using high-speed video camera recordings. The high-speed video image was formatted in a bitmap graphic with 312 × 260 pixels. The dynamic contact behaviour was recorded, starting from before the impact until after the impact of the ball.

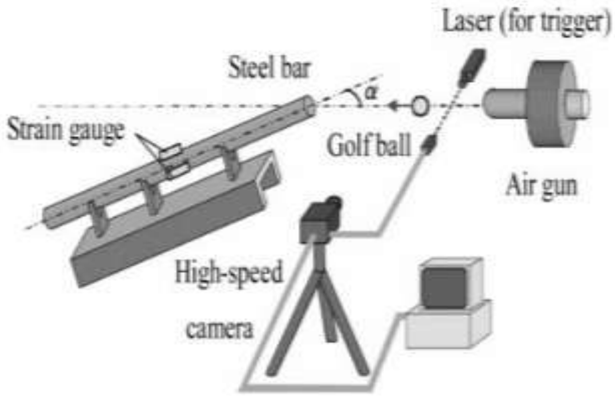


Figure 2.6: Experiment apparatus by Tanaka et al. (2006) for determining the impact properties of a golf ball

Other than the high-speed camera, another equipment attached to the apparatus is a sensor. The impact of the ball onto the force plate is a popular method that has been used in some sports research to investigate the characteristic of the ball impacts (Bao & Yu, 2015). Cross (2006) used tennis balls to impact onto a steel plate and attached to the force plate. In the study, the laser beam was once employed to record the time and speed at which the ball handed thru the beam. Figure 2.7 shows the experiment set up by Cross on testing the ball impact the circuit board.

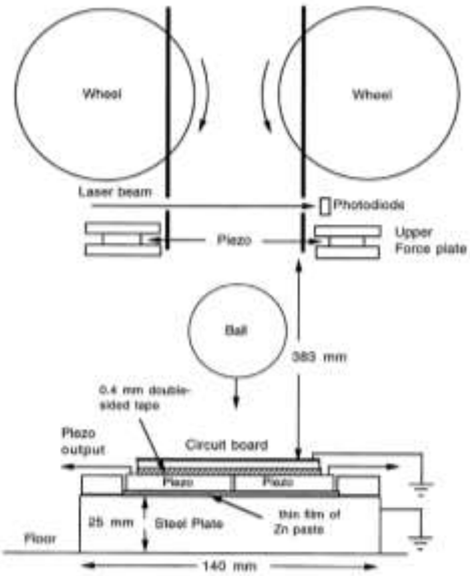


Figure 2.7: Experiment set up by Cross (2006)

Other previous methods had engaged the speed monitor. With this method, two-speed monitors were used, which stood equally between the machine and a rigid wall. This equipment was used to determine the velocity impact before and after (Burbank & Smith, 2012). Besides that, infrared light gates were employed to measure the velocity impact before and after a collision with the rigid wall (Smith & Duris, 2009).

2.4.1 The Coefficient of Restitution (COR)

The coefficient of restitution (COR) can be expressed as the ratio of the inbound speed into the rebound velocity. The COR is an accessible parameter used in many collision models for collision without friction and is COR usually utilized as constant values between zeros to one. The COR also recognized as the predominant energy loss due to the action in an ordinary direction. The manufacturer can increase the COR of a sports ball with the aid of reducing the deformation experienced under a load.

The COR is usually denoted by e and to comply COR with the work-energy principle, the condition $0 < e < 1$ with the end conditions corresponds to perfectly plastic $(e = 0)$ and perfectly elastic impact $(e = 1)$. As COR performs a key the position in measuring the energy loss at some stage in the collision, COR is usually defined by;

By the conservation of energy:

$$e = \sqrt{\frac{\frac{1}{2}mv_f^2}{\frac{1}{2}mv_i^2}} = \sqrt{\frac{v_f^2}{v_i^2}} \qquad \text{Equation 2.1}$$

$$e = \sqrt{\frac{mgh_f}{mgh_i}} = \sqrt{\frac{h_f}{h_i}} \qquad \text{Equation 2.2}$$

The COR depended on many elements, such as the mechanical properties of the ball, the shoes, the foot upon impact, the method velocity, the period of contact, and possibly, friction. Cross (1999) determined that the COR is associated with energy loss for the duration of the impact. He used a dynamic hysteresis curve to show the energy loss. The different COR was affected by the different types of materials of the balls. The plasticine ball gave the lowest COR since the collision is inelastic. Bao (2015) mentioned that through increasing the initial velocity, extra energy would be dissipated, main to a reduce in the COR.

Decreasing the COR by increasing velocity have been proven by the method of kicking (Andersen et al., 2008). Andersen et al. (2008) conducted a pendulum experiment with toe and instep kicking. In both, toe and instep, the COR dropped with increased impact velocity. The COR of the ball impact on a hard surface is between 0.5 and 0.8 (Cross, 2010).

2.4.2 Deformation

Deformation plays a significant role in the impact of mechanics. Ball deformation results from the abrupt deceleration connected with its impact against another body. It can simplify the dynamic compression of the ball. Deformation is evident from a reduction in the ball's diameter perpendicular to the impact surface. The measurement of ball deformation is an essential parameter in analyzing the behavior of the ball.

Deformation influences the trajectory strike of the direction of the ball. To analyze the maximum ball deformation quantitatively, the maximum normal (d_n) and tangential (d_t) deformation ratios can be calculated the use of the following equations:

$$d_n = 100|D_n - D_o|/D_o \quad \text{Equation 2.3}$$

$$d_t = 100|D_t - D_o|/D_o \quad \text{Equation 2.4}$$

D_0, D_n and D_t, are stated as initial ball diameter, maximum ball span normal, and tangential to the flat surface, respectively.

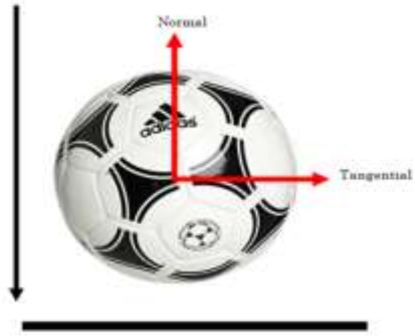


Figure 2.8: Normal and tangential direction

The study showed that impact velocity had a profound effect on the measurement of deformation. The reduced area of the ball associated with increased local ball deformation (Price et al., 2006).

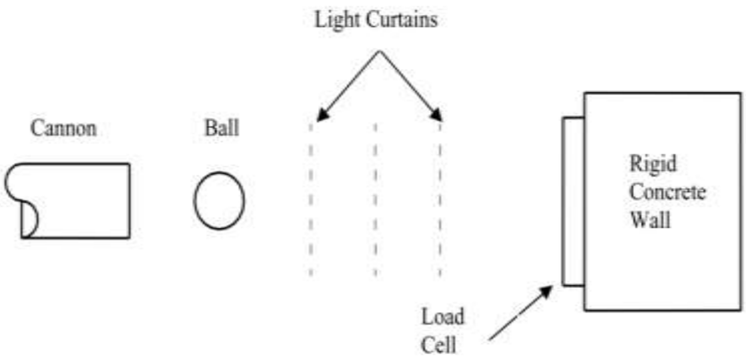


Figure 2.9: Experiment test setup for dynamic compression by Duris et al. (2015)

Other than the increasing velocity, the deformation effected by the sorts of distinct boots even at the equal kicking foot velocity. Aris et al. (2013) showed that the increase in ball deformation also increases the COR. The difference patterns value of COR is affected by the differences in materials construction properties of the boots. Types of kicking also influence the value of the velocity of the ball and directly affects the value of deformation. Shinkai (2009) showed that the foot velocity of instep kicker higher compared to side-foot kicks.

2.4.3 Contact Time

Contact time is a measurement of the ball compressions. Contact time can be defined as the time of the object contact with the impact surface or in simple terms: impact duration. The primary measurement techniques to determine the contact time are force plate, high-speed imaging and electrical circuit (Roberts et al., 2011). Research showed that contact time increases as the COR and deformation decreases.

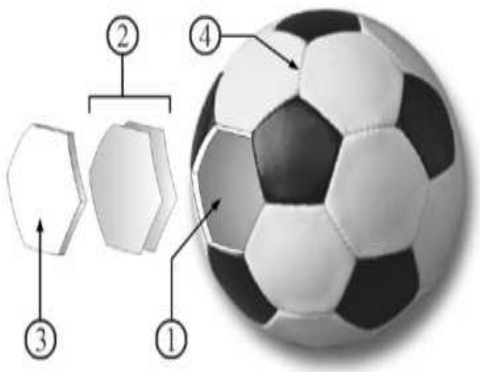
Few researchers have conducted experiments to determine contact time recently. Golf, baseball, tennis, and football are among the sports balls that have been tested by researchers. From that research, the impact duration time was measured in milliseconds (ms) ranged from 0.4 - 12.4 ms. Footballs showed the highest impact duration compared to other balls. The use of high-speed imaging is a frequent method used to determine the contact time of an impact. The difficulties and the limitation used in this method arise when capturing more dynamic impacts of fast sports such as tennis or football in real situations (Hanson et al., 2012).

2.5 Finite Element Modelling of Sport Balls

Computer modelling, particularly Finite Element Analysis (FEA) has been considerably used within the sporting goods industry to aid in the design manner of new products. A finite element (FE) modelling was once an aid in the design and development of products by allowing engineers to analyze the mechanical properties of the products that supply the preferred overall performance characteristics without making physical prototypes.

FE modelling is a useful tool in optimizing overall performance characteristics; as it is additionally a useful approach that can be used to reduce the time and financial price of designing and manufacturing a new product. The use of finite-element modelling (FEM) to design the virtual structure and behavior of solid sports balls is well established, due to the need to apprehend the relationship between characteristics and ball performance by both manufacturers and governing bodies (Ranga & Strangwood, 2010). The manufacturer is constantly searching for greater energy to improve the performance of the balls. However, governing bodies want to have an exact perception of ball behavior.

Price et al. (2006) examined a model of soccer balls and the effects of the stitched design of a ball. The models were developed as hyperelastic and viscoelastic materials. The ball models were developed in icosahedron geometry. It showed stitches on the football, the effect on the deformation of the ball, and showed the lower energy level. To understand the mechanics of sports equipment, the FEA had been applied by many researchers. Munroe et al. (2012) applied FEM in the research for a baseball. The FEM of a baseball assumes to be a single viscoelastic material where the respective material properties have homogenized.



No	Layer Name	Material
1	Bladder	Natural rubber latex.
2	Inner	2 layers of knitted fabric
3	Outer Panel	Intermediate fabric layer and polymer layers.
4	Stitching	Polyester fibre based yarn

Figure 2.10: Model detailed by Price et al. (2005)

Allen et al. (2012) developed and validated the FE model of a cricket ball/bat impact. Their finding showed that the FEM approach was once in a position to accurately predict A COR along with the length of the blade (ACOR is defined as the ratio of a rebound to inbound ball velocity).

FEM is also able to be used to validate the simulation using the human model. Hassan (2015) applied the FEM analysis on the research in football heading. The research built a soccer-heading simulation. The model can be used to validate the result during a soccer ball heading. Sadaq et al. (2014) used FEM to validate the impact test motorcycle helmet in a different angle. The results showed a comparison between two materials in term of deformation and strains.

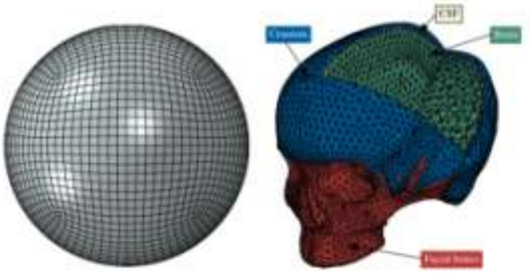


Figure 2.11: The FEM of the soccer heading simulation by Hassan et al. (2015)

2.6 Drop Test Simulation

A sizeable problem of each the industry and government is the improvement of merchandise compromising the security of users. With the development of society, humans have extra strict needs for passive protection and ergonomics. The improvement of computational methods enables the deepening exploration of physics through simulations of a number of work conditions. Drop test simulation is one of the techniques commonly used in trying out of the strength of the materials. The drop test analysis is used to evaluate the impact of different drop scenarios. In Solidworks simulation, the software solves a dynamic problem as a function of time.

The common equations of motion:

$$F_I(t) + F_D(t) + F_E(t) = R(t) \qquad \text{Equation 2.5}$$

$F_I(t)$ is the inertia forces, $F_D(t)$ is the damping forces, and $F_E(t)$ is the elastic forces. All of these forces are time-dependent.

In static analysis, this equation reduces to $F_E(t) = R(t)$ for the reason that the inertia and damping forces are ignored due to small velocities and accelerations. In a Solidworks drop test, it uses an explicit time integration method. It routinely estimates the critical time steps based on the smallest element size and makes use of a smaller value to prevent divergence. The programme internally adjusts the time steps as the solution progress.

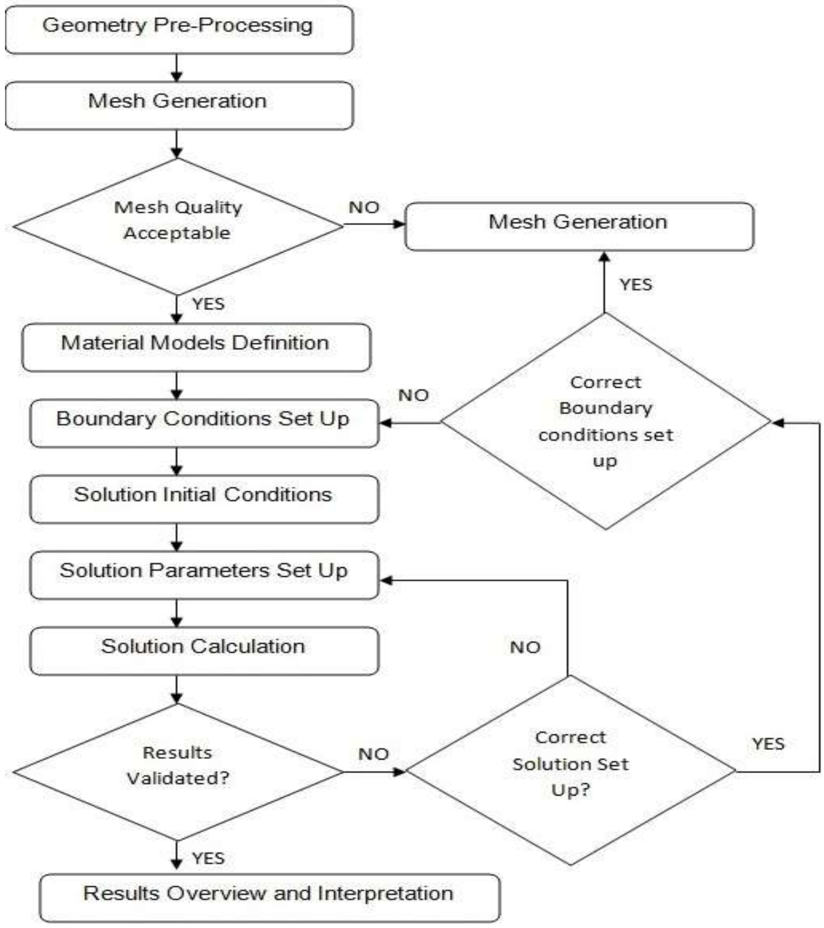


Figure 2.12: Explicit analysis methodology (Todorov et al., 2017)

2.7 Summary

This chapter reviewed published literature related to the development of the dynamic testing criteria for sports balls. There is relatively little-published literature on the impact test on sports equipment. The rubber vulcanized ball was designed and built by Charles Goodyear in era 80s. He was the first inventor for the first vulcanized rubber bladder by eliminating the depending on pig bladder. The impact test is standard test which usually used to determine the characteristics of the materials. Ahmad and Taha (2006) testing impact on *sepak takraw* ball for determine the impact force, contact time, the coefficient and also the deformation. While Koizumi et al. (2014) conducting test on soccer ball impact on various types of balls. Haron (2012) and Bao (2015) conducting on impact test of sport equipment on the different types of impact surface. Deformation was a significant role in the impact of mechanics Zhang (2014) and Aris (2013). FE modeling is a useful tool in optimizing performance characteristic of sport equipments. Ranga and Strangwood, (2010), proven it by testing the performance of Criket sport equipments. Price (2005) conduct testing on the effect of stitched design on the soccer ball materials. It prove that, from simulation the effect on the deformation and the energy level of the ball. All this information was collected from journals. This information is essential to proceed to the next stage of this research. All the information focuses on properties on the sports equipment after impact.

CHAPTER 3

METHODOLOGY

3.1 Chapter Overview

This chapter outlines the equipment and methodology used to capture the experimental data. Also, FEM modelling procedures and techniques are described. The analysis procedures on how the experimental data are also described.

Figure 3.1 shows the flowchart of project methodology which is to test the real model of Futsal ball to compare with the model of Futsal ball. The real Futsal ball undergoes the impact test to determine the impact characteristics. The Solid Model of Futsal ball developed using the Solidwork software, and test the model with the Solidwork Software in impact test.

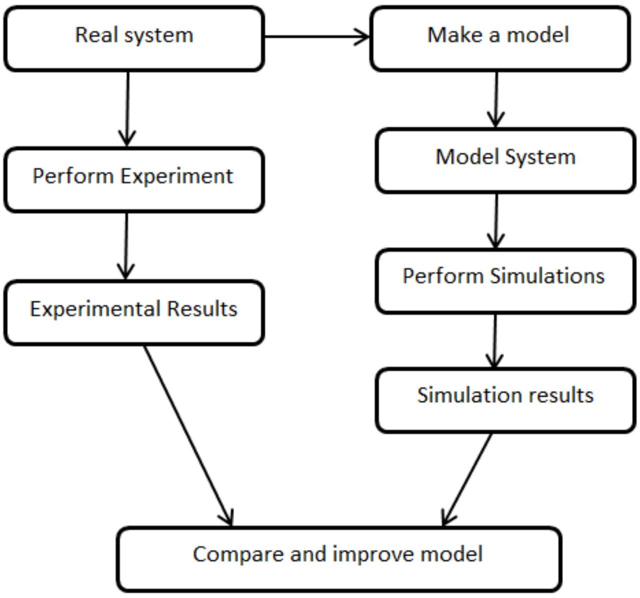


Figure 3.1: Flowchart Methodology

3.2 Sample Size

The three different heights for the free fall test in this study is 0.5, 1.0 and 1.5 meter (Ismail et al., 2010). A total of 105 free fall test were performed during the experiment, with 35 free falls for each height.

The ball used for this study was the Adidas Futsal ball size four by using the Jabulani® type. Jabulani® is a ball manufactured by Adidas, and it used to be the identical design used in the authentic suit ball for the 2010 FIFA world cup. The Jabulani® ball was configured from eight triangular and tripod-shaped panels. The bounce of the football ball is 50 - 65% much less than a standard football.

Table 3.1: Details of futsal ball used in this experiment

	FIFA-Approved	Measurements
Circumferences	62.5 - 63.5 centimeter	63 centimeter
Weight	410 - 430 grams	430 grams

In order to get consistent data, the ball was dropped onto the equal face in their initial conditions, the X was marked on the ball. The study was performed in the Mechanical Laboratory of the Faculty of Engineering, UNIMAS.

Figure 3.2: The Adidas Jabulani® futsal ball size four

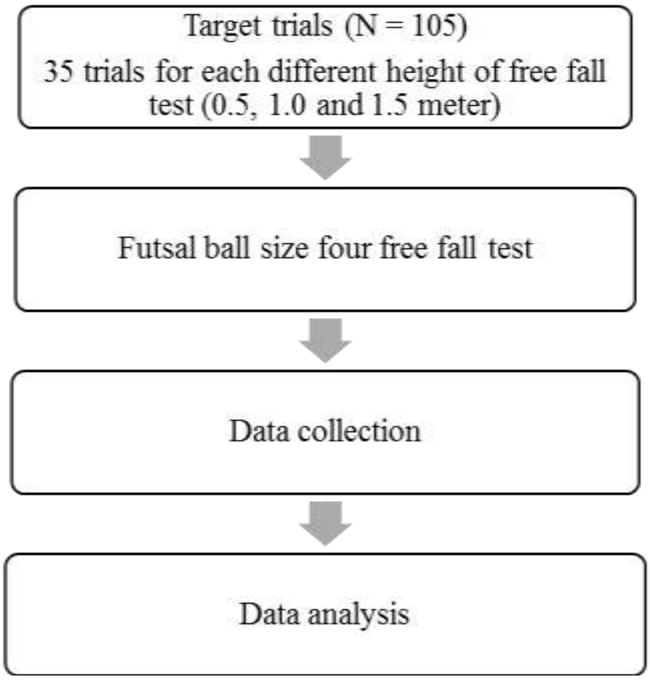


Figure 3.3: Flowchart of assessment trials (N = 105).

3.3 Instrumentation

3.3.1 Futsal Ball

Adidas® futsal ball size four was the central equipment used in this study. The futsal ball was marked at the bottom in order for it to be dropped in the same initial position for the test. Size four Futsal ball is a FIFA standard Futsal ball which is smaller than a traditional size four ball and bigger than a size three ball. The Futsal ball sizes four have a specific bladder that is filled with foam to make the ball heavier and have less bounce.

3.3.2 Drop Impact Apparatus

The drop impact apparatus with a height of 1.8 meter was constructed in order to run the free fall impact test of the futsal ball.

Figure 3.4: Drop impact apparatus

3.3.2.1 Steel Plate

A steel plate with a thickness of 0.01 meter as the center medium for the impact of the futsal ball (Ahmad & Taha, 2006).

3.3.3 Video Camera

Sony camera Mark IV employed for this experiment. The video camera needed to record the ball before and after impact. The Sony camera Mark IV was able to record up to 1000 high frames rate.

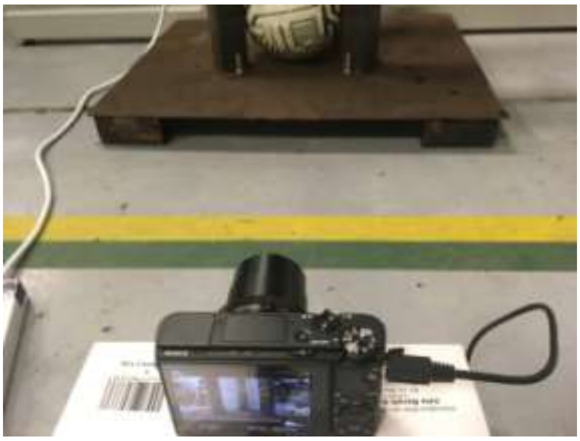


Figure 3.5: Sony camera Mark IV used to capture the ball before and after the impact on the steel plate

3.3.4 Motion Sensor

A SPARKvue motion sensor (PS-2103A) was attached at the top of the impact apparatus. The motion sensor was used to record the height and time of the futsal ball during the free releases.

Figure 3.6: SPARKvue motion sensor at the top of the apparatus

3.3.5 Sparco Tools

The Sparco software was used to analyze the height of the ball before and after impact. Besides that, this software was also used to determine the contact time of the ball before and after impact.

3.3.6 ImageJ Tools

ImageJ software (ImageJ 1.51j8) was used to measure the normal and tangential diameter of the futsal ball after impact.

3.3.7 Video Converter

Free video converter v. 5.0.101 build 201 was used to convert the video into the JPG photo format.

3.3.8 SolidWorks 2015

SolidWorks 2015 x64 Edition was used for the modelling and simulations of the futsal ball.

3.4 Sample Preparation

In this quantitative research, the sampling technique used was purposive sampling. Purposive sampling can be used with both qualitative and quantitative research techniques. The criteria chosen for this purposive sampling are the elasticity of the futsal ball, the stress and the kinetic energy produced during the ball impact onto the steel plate. This sampling method was used to focus on the three different drop height for a futsal ball. The purposive sampling was used as a sample chosen from the drop height of the ball from three different heights, 0.5, 1.0 and 1.5 meter.

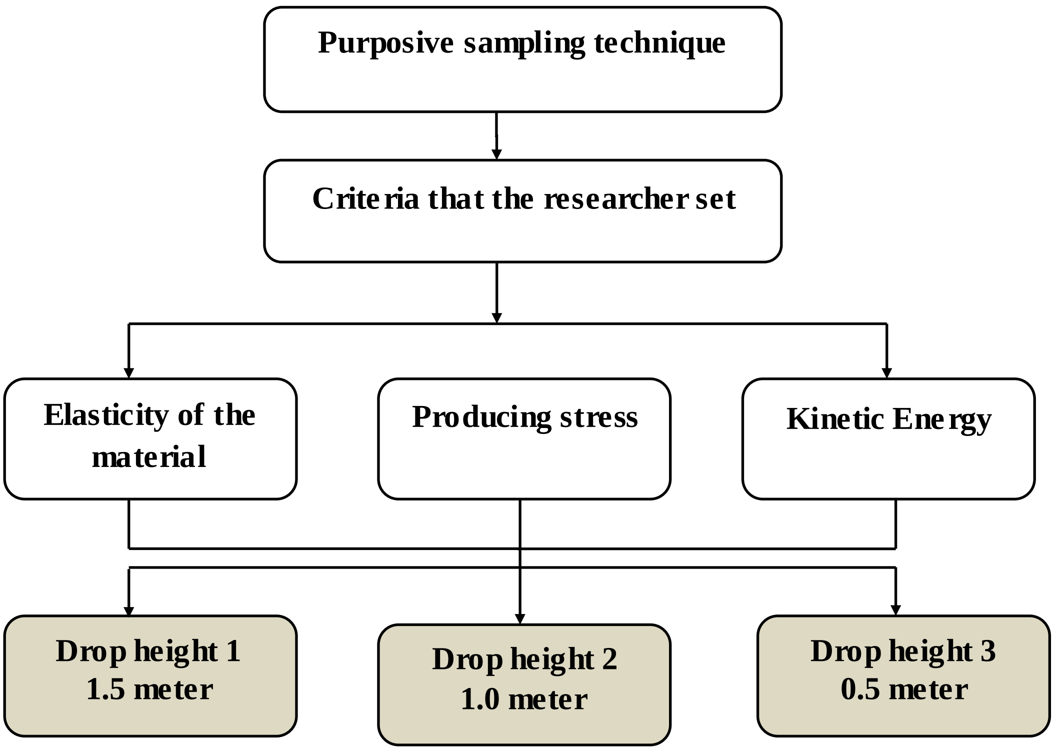


Figure 3.7: Sampling process

3.5 Data Collection

Before model development, a test experiment was once designed and carried out to investigate the impact behavior of the futsal ball in order to set up a benchmark that can be used to validate the developed ball model. Generally, the equipment used for the experiment consisted of a SparkVue sensor mounted on a brass rod. The digital camera stands 0.5 meters from the apparatus. In order to achieve accurate data, the ball was dropped with the identical face and predetermined height.

3.5.1 Procedure

The goals of this research are to measure the deformation, the coefficient of restitution (COR) and the contact time when the futsal ball impacts the steel plate surface.

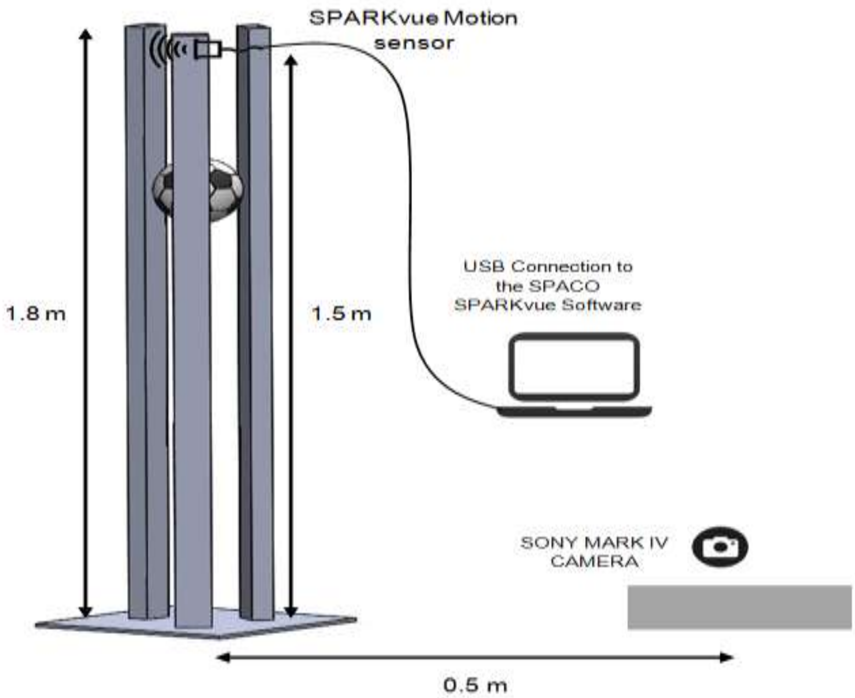


Figure 3.8: Schematic diagram of the ball drop

The test set up for the free fall futsal ball is shown in Figure 3.8. The Sony Camera Mark IV was placed 0.5 meter from the apparatus. The SPARKvue motion sensor was attached at the top of the apparatus, with a USB connection to the laptop, for the analysis of the height of the ball during free releases with the SPARCO software.

The measurement of the height at the apparatus was measured with the measuring tape. Thirty-five trials were made to get the impact characteristics. The reasons behind the thirty-five trials were to increase the validity and reliability of the reading. The futsal ball will drop with the mark at the bottom as the center of the impact. The camera was set up in front of the apparatus. The data will be analyzed with the SPACO and ImageJ software to find the coefficient of restitution, deformation, and the contact time value. The video was recorded using the SONY camera MARK IV, then converted with the JPEG video converter, to produce the single photo. Figure 3.9 show the process of the data collection from the conducting of the drop test experiment.

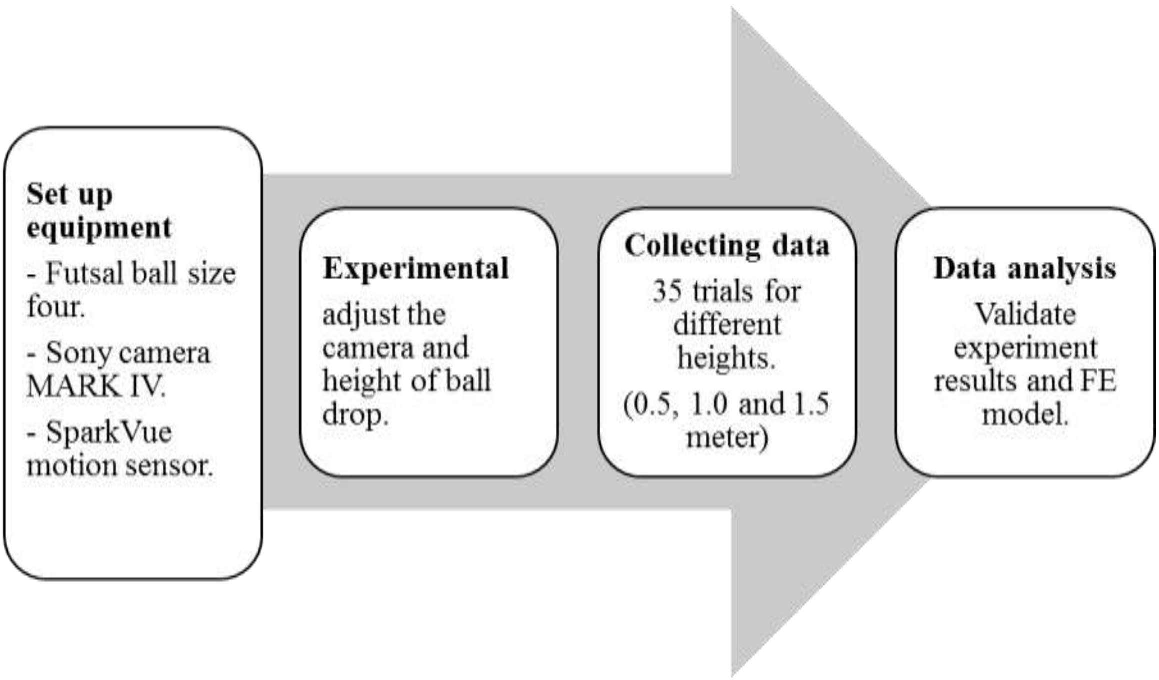


Figure 3.9: The process of the data collection

3.6 Dynamic Analysis

The information was analyzed using the Statistic Package for Social Science 21 (SPSS). The evaluation included the calculation of mean and correlation to check on the normality of the data.

3.6.1 Deformation

Video techniques are universally applied across the sports equipment industry to analyze the deformation characteristics of sports equipment. The Sony Mark IV camera was used to capture the impact of the futsal ball size four when it hits the steel plate. Sony Mark IV was set up in the slow-motion mode, the camera's capability allows it to go to 1,000 frames/sec (960 fps).

The video that was captured using the Sony Mark IV then transferred to the computer and converted into single photos. The free software video converter V. 5.01.1 build 201 was used to convert the video into a single JPG photo format. The first drop photo was chosen as the sample for the drop for that height.

Figure 3.10: Sample first drop of the ball for 1.5 meter (random from 35 drops)

Lastly, the JPG photo was analyzed using the ImageJ software to determine the normal diameter. The deformation of the futsal ball was calculated using the formulas 2.3 stated in Chapter 2. The initial normal diameter, (d_n) recorded was 208.46 milimeter. The initial diameter for the futsal ball was determined with the single photo as shown in Figure 3.11 of the futsal ball captured in the apparatus with photo pixel 624 × 392. The initial diameter information from that photo was as a reference for the initial diameter used in the calculation. Figure 3.11 below show the screen-shoot image analysis by the ImageJ software.

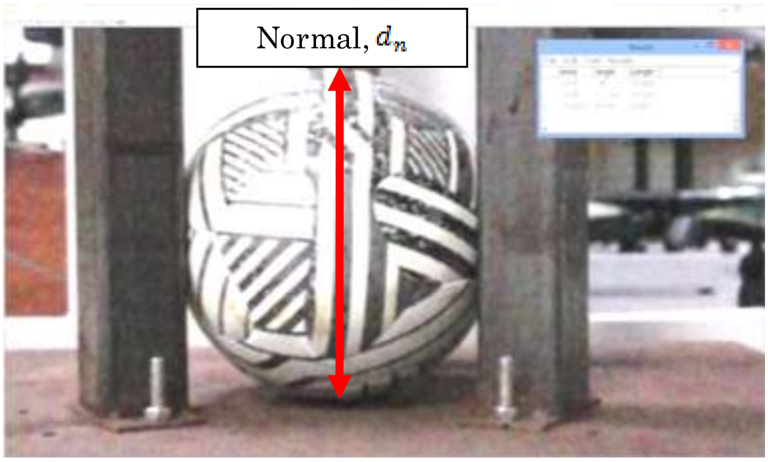


Figure 3.11: A normal diameter measured using the ImageJ software

3.6.2 Coefficient of Restitution (COR)

SPARKvue motion sensor (PS-2103A) was used in the research to determine the height before and after impact and SPARKvue motion sensor operation in 10Hz sample rate. It was in periodic sampling mode and analyzed using the Sparco Software.

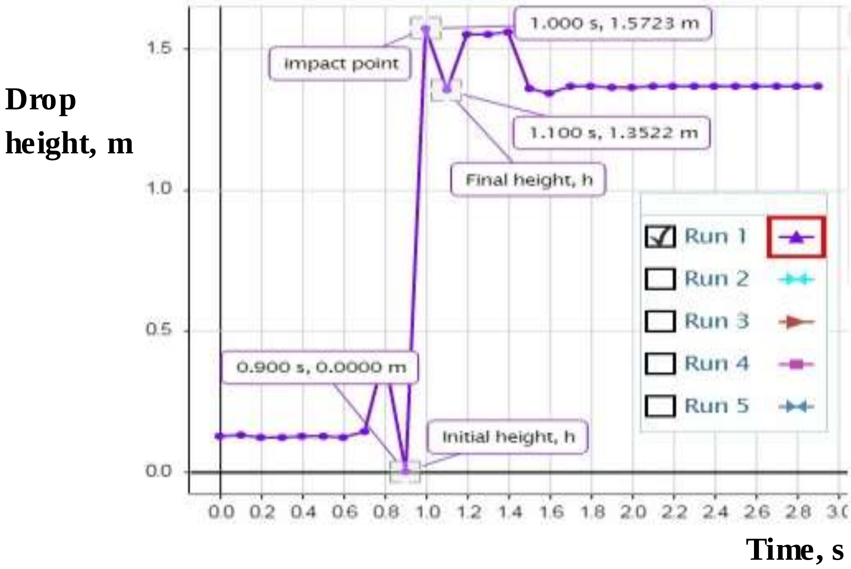


Figure 3.12: Movement of the ball drop by the motion sensor analysed with Sparco Software (Random graph from drop height 1.5 meter)

Figure 3.12 show the screen-shoot of the movement of the ball drop versus time impacting of the stel plate. The photo was captured in the sparco software. Referring to Figure 3.12, the initial drop height was 1.5723 meter, and the ball was dropped against the gravity, so the air resistance is negligible. The height of the ball after the first impact was 0.2201 meter. The steps analysis was done to all the repetition of the drop height (N =105). The coefficient of restitution of the futsal ball has once calculated the usage of the formula:

$$e = \left(\frac{h_2}{h_1}\right)^{1/2} \qquad \text{Equation 3.1}$$

The Equation (3.1) derived is 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 the ball, the longer it bounces.

3.6.3 Contact Time

The use of high-speed imaging is a frequent method employed to determine the contact time of an impact. The difficulties and the limitation used this method arises when capturing more dynamic impacts of fast sports such as tennis or football in real situations. For this research, the contact time was considered as the time difference between the before and after impact.

The contact time for this work was determined by using the SPARKvue motion sensor that was attached to the Sparco software. That attachment was used to determine the velocity and drop height before and after impact. Referring to Figure 3.12, the initial time before impact was 0.900 second, while after the impact the time was 1.000 second. The contact time for that particular drop was 0.100 second. This steps analysis was done to all the repetitions of the drop height (N =105)

3.7 Modelling of Futsal Ball

Figure 3.13: A solid model of futsal ball size four

The model of futsal ball size four was prepared in Solidwork 2015 software, and then it was run in Solidwork simulation for a drop impact analysis. An impact analysis was performed with the same three different heights as in the experiment. The model consists of 32 panels made up of 12 pentagons and 20 hexagons. The edge panels were applied with fillet and are sewn together using 630 double stitch-double knots. In standard balls, double knots make the ball lasts longer. The model and the wireframe of futsal balls is as shown in Figures 3.13 and Figure 3.14, respectively.

The table 3.2 show the mass properties of Futsal ball developed in Solidwork Software. The mass the of modelled ball was 0.341 kilogram, with the volume and mass density are 0.355 m^3 and 0.961 kg/m^3 respectively.

Table 3.2: Mass properties of futsal ball

Mass :	0.341 kg
Volume :	0.355 m^3
Density :	0.961 kg/m^3

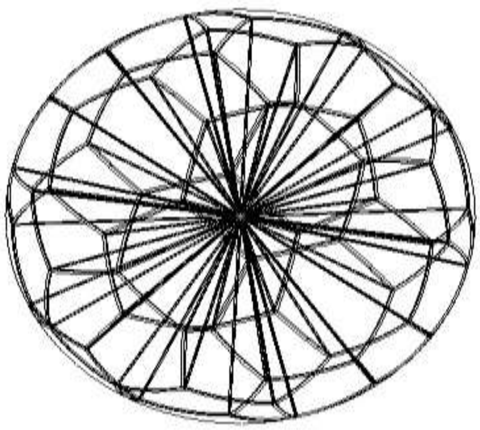


Figure 3.14: Wireframe model of futsal ball size four

The fully-modelled futsal ball consists of three standards elements. Point 1 is a solid that is constructed as the bladder of the futsal ball, which usually contains microfiber. Point 2, is a filled edge, which assumed as a stitching-double knot. Lastly, a point 3 outer layer, the surface as PU surface, is typically made of synthetic leather in polyurethane (PU).

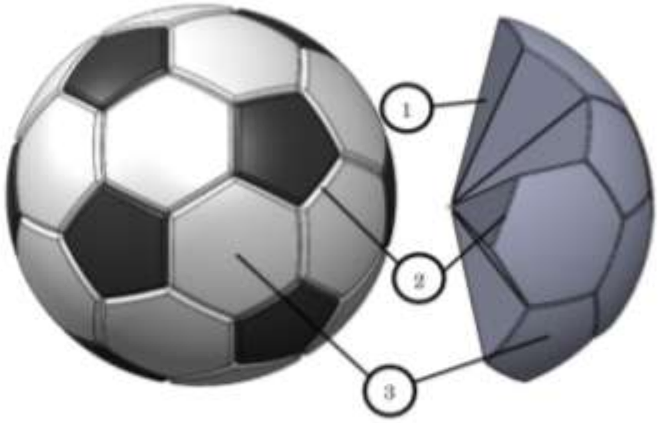


Figure 3.15: Detailed of the design

Table 3.3 show a PU Futsal ball size four model information from the Solidwork Software. The analysis was conducted in impact analysis as a drop test; with the meshing type was solid mesh. The solution and result time for the simulation was 300 microseconds and 50 microseconds respectively.

Table 3.3: Model Information

Body Name :	PU Futsal Ball Size four
Analysis :	Drop test (Impact Analysis)
Mesh Type :	Solid Mesh
Solution Time :	300 microsecond
Result Time :	50 microsecond

The finite element modelling approach employed in this research reveals the interaction between the futsal ball size four and the impact plate. The work that has been confirmed in the detailed experimental verifications is also presented in this work. The techniques presented in this chapter, therefore, provide the basis for the improved understanding of detailed mechanics occurring during impact.

3.8 Futsal Ball Modelling

The futsal ball size four was developed by Solidworks 2015. A futsal ball consists of bladder typically inside the ball. That is assumed to more robust compared to the actual soccer balls. It also more bounces compared to football. The FE model presented here is a solid ball which was developed in dodecahedron that consists of 32 panels made up by 12 pentagon panels and 20 hexagons panels.

Figure 3.16: The solid model of futsal ball size four

3.8.1 Finite Element Modelling of Futsal Ball Size Four

The developed FE model includes designated ball geometry and demonstrated material parameters. The development of the FE model consists of the development of geometry and the undertaking of material properties.

Figure 3.17: Prepared geometry model

During the simulation, the temperature effect was not considered. The initial analysis velocity (just before falling object hitting the ground) was once calculated as follows:

$$V_0 = a_g \times \sqrt{\frac{2 \times h}{a_g}} \qquad \text{Equation 3.2}$$

Where h = total height of the drop.

a_g = gravitational acceleration (9.81 m/s^2)

3.9 Finite Element Analysis (FEA)

Finite element analysis (FEA) has been universally implemented in the simulation of sports balls, including golf-ball and a softball. The simulation is carried out and compared to experimental data. The finite element method is a powerful engineering analysis tool capable of evaluating the velocity and deformation, which are of interest in the impact analysis. In this numerical technique, all of the vital influence on the impact are considered simultaneously, and the output permits a detailed analysis of the interaction between the impacting bodies.

3.9.1 Solidwork Simulations

In this work, Solidwork 2015 x64 edition was employed for the simulation works. First steps in the finite element analysis process are pre-processing. The pre-processing contains four steps that are needed to apply in order to create an FE model for use in the steps of the simulation solution.

The geometry creation is the first step taken to create a solid geometrical model of the object, generally known as a part. Next, are the assignment of the material property. This step assigns the appropriate material properties to the part to be analyzed. Following this, the boundary condition for the simulation processes defined.

Some of the boundary condition needs to be considered for the simulation drop test are, the plane direction, impact velocity, gravity directions and solution time, as all of this lead to the result. The final step in this process is mesh generation, that is to discretize the part into the element as shown in Figure 3.18.

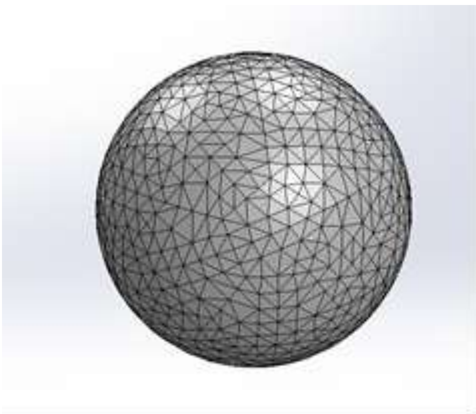


Figure 3.18: Mesh Model

The next process on the simulation of drop test is a simulation, which is the process of running the simulation. In this process, the computer solves the simulation problem and generates the results for the post-processing step. The second last process for the simulation drop test is post-processing, which is a process for the results of interest. The last process is a validation of results. In this process, all the results of interest were generated. Finally, the results from FEA and Analytical are compared.

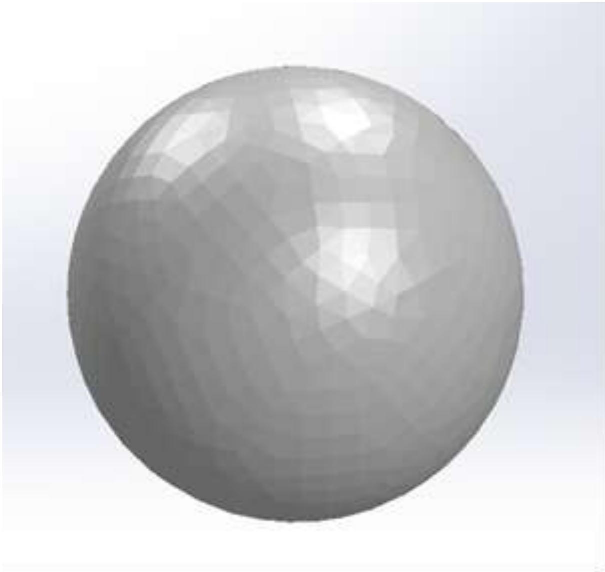


Figure 3.19: Deformed shape

3.9.2 Material Properties

The determination of appropriate material properties is a critical aspect of all analytical impact modelling. Latex Rubber (NR), Butyl Rubber (IIR) and Natural leather were selected as these material are generally used in the fabrication of the football materials. Nowadays, rubber is an essential material for manufacturing a wide variety of industrial products. The rubber properties for NR, IIR and Natural leather used for the simulation are stated in Table 3.4.

Latex rubber (NR) or known as Natural rubber is the non-synthetic rubber that consists of a polymer of the organic compound isoprene with minor impurities of other organic compounds, such as water. Elasticity is one of the vital quintessential houses of natural rubber. NR is unique to the extent that it can be distorted, and the rapidity and degree to get better to its original form and dimensions. NR is typically used in the massive truck, and earthmover tires which require low heat buildup and maximum reduce resistance. IRR is additionally used in industrial goods, engineering products, for its resilient load bearing and shock or vibration absorption components.

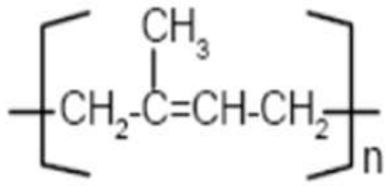


Figure 3.20: Formula for Latex rubber (NR)

Butyl rubber (IIR) is a synthetic rubber that is usually used for the bladders in sports activities balls to provide a sturdy and airtight internal compartment. IIR also has low gas permeability, and collectively with its flexibility makes it the ideal material for inner tubes of tires or other high-pressure tubes. Other than that, IIR’s very gradual resilience makes it appropriate for shock absorption, vibration damping, and isolation application.

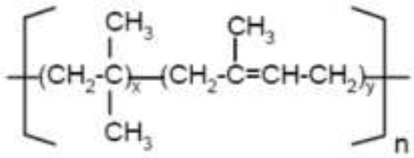


Figure 3.21: Formula for Butyl rubber (IIR)

Natural leather is a long-lasting and flexible material created by using tanning animal rawhides. The leather is used to make a number of items, which includes footwear, car seat, clothing, and furniture. Historically, the first ball was once created from pig or cow bladders.

Table 3.4: Material properties of the constructed FE model

Material properties	Butyl Rubber (IIR)	Latex Rubber (NR)	Natural Leather
Young modulus, E (KN/m^2)	1 – 2	1.5 – 2.5	100 – 200
Poisson ratio, ν	0.48 - 0.50	0.48 – 0.50	0.46
Density, ρ (kg/m^3)	900 - 920	920 - 940	810 -1050

3.10 Summary

This chapter describes the successful experimental procedures and equipment used for completing this project. It shows the whole stage of the experiment and the analysis for this project. It is done to achieve the main objectives of this project that is to investigate the impact characteristics of futsal ball size four and the simulation of its impact characteristics. The impact test experiment was conducted at Engineering Lab of Unimas. Impact apparatus with the height of 1.8 m was developed for the impact test which the Futsal ball was tested in three different drop heights: 0.5, 1.0 and 1.5 meter, with 35 repetitions for each height. After the impact test conducted, the modelling of futsal ball was started with the Solidwork software. The simulation on impact test also conducted by employed the SolidWork Simulation software. The next chapter will discuss the result on the impact experiment and the simulation analysis for the futsal ball size four.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Chapter Overview

The study used to be performed to inspect the dynamic properties of the futsal ball on the different peak of the ball drops. The experimental and simulation data had been analyzed the usage of the Statistical Package for Social Science (SPSS).

4.2 Experimental Results

In this study, the test is separated into three different drop heights. The entire test consists of 35 trials, each of the drop heights, which is 0.5, 1.0 and 1.5 meter. There was a total of 105 free fall test in this study (N = 105). This study used Pierson's correlation, r to analyze the data.

4.2.1 Coefficient of Restitution (COR)

The coefficient of restitution value always less than one due to the first translational kinetic energy that lost to the deformation. It can be more than one if there is an energy gain during the collision.

The coefficient is related to kinetic energy by, $e = \sqrt{\frac{KE_{(after\ collision)}}{KE_{(before\ collision)}}}$ Equation 4.1

During the drop test, before the ball is released, the futsal ball stored potential energy. The higher the ball, the more it releases potential energy. When the ball is released, the futsal ball dropped against the gravity, and the velocity increased. The velocity of the ball increased the higher the ball is dropped. After the impact, the ball converts the stored energy into the energy of motion and impacts the steel plate.

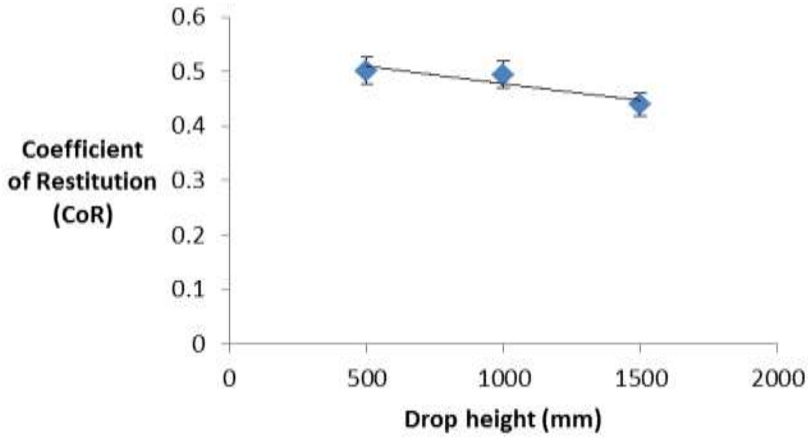


Figure 4.1: Ball drop height (mm) vs Coefficient of Restitution (R^2 = 0.8348)

Figure 4.1 shows the graph of drop height vs Coefficient of Restitution of the futsal ball size four. From the graph, the R^2 was 0.8348. The relationship between the two variables have a 83% of variation in the data. Generally, the Coefficient of Restitution decreased with the increase in drop height at lower 0.5 meter, with a value of 0.5013 and plateaued at higher 1.5 meter with the value of 0.4394. The decreased Coefficient of Restitution is assumed to be due to the different force of the futsal ball during the impact. The results obtained agreed with previous work carried out by Bao et al. (2015), Thomas Bull Anderson et al. (2008) and Hasanuddin et al. (2015).

The formula calculates the energy losses (Rod Cross, 2006):

$$\textit{Energy loss} = (1 - e^2) \times 100\% \qquad \text{Equation 4.2}$$

From the calculation, from the drop height of 0.5 meter, the energy loss was 74.87%, and the maximum energy loss was at the drop height of 1.5 meter, at 80.69%. The value of COR from the futsal ball size four during impact was in between 0.4 to 0.5. It shows that the futsal ball size four used in this experiment was developed using an elastic material.

During the impact, the less elastic material can convert a large amount of kinetic energy into heat. Other than that, during impact, the elasticity of the material may be absorbed by the kinetic energy for large deformation. As an object dropped from a resting position, its gravitational potential energy is converted to kinetic energy. From the value of COR futsal ball size four, it can be perceived that the drop test is an inelastic collision and that the futsal ball does not conserve energy, but it does conserve momentum. The energy was lost to the environment, or transferred into other forms such as heat during the impact.

From the coefficient of restitution, 1.5 meter has shown the highest energy loss as it is equivalent to 80.69%. It is followed by 1.0 meter with 75.58% and 0.5 meter with 74.87%. The results obtained agree with the results reported by another researcher the less value of the coefficient of restitution, the large amount of energy absorbed during the collision. From this result, it can be concluded that the coefficient of restitution was affected by the impact velocity and the nature of the impacting surface.

4.2.2 Deformation

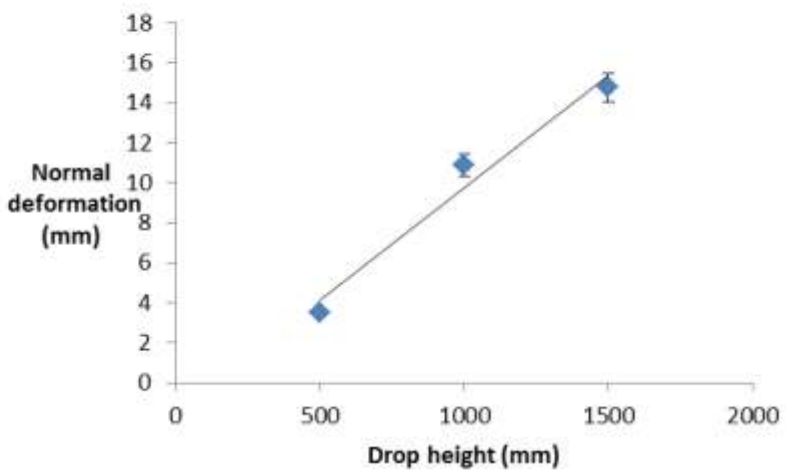


Figure 4.2: Ball drop height (mm) vs Normal deformation (mm) (R^2 = 0.9694)

Figure 4.2 shows a normal deformation for the drop test of the futsal ball size four. From the graph, the R^2 was 0.9694. The relationship between the two variables has a 96% of variation in the data. As can been seen, normal deformation increases with an increase in drop height during the drop test. The increased deformation is assumed to be due to effects of the kinetic energy during the impact, which is the energy transition, from the potential energy to kinetic energy. The results obtained agreed with previous work carried out by Ahmad et al. (2012), Aris et al. (2013) and Price et al. (2006).

From the results, the normal deformation showed the highest deformation 14.7615 milimeter at 1.5 meter. The highest deformation was shown at the highest drop height. The Kinetic energy during the impact was absorbed during the highest deformation, as the value of COR at 1.5 meter (COR = 0.4394) was less compared to 0.5 meter (COR = 0.5013).

4.2.3 Contact Time

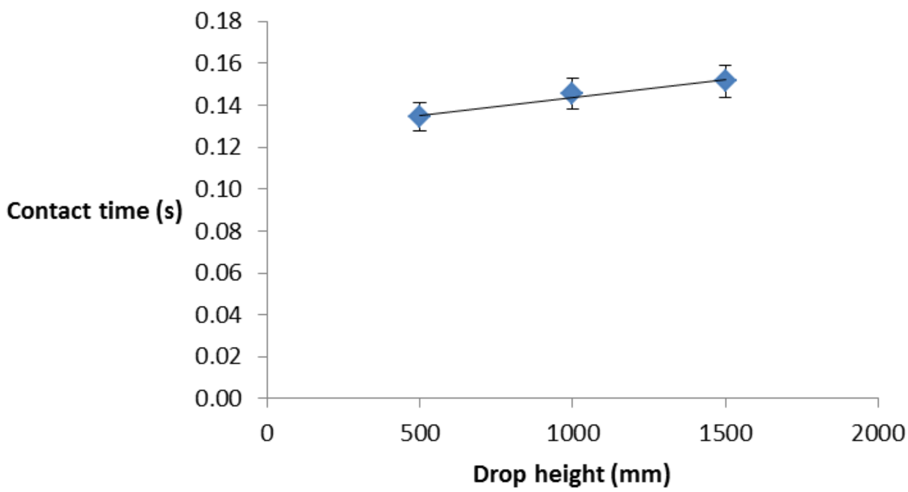


Figure 4.3: Ball drop height (mm) vs Contact time (s) (R^2 = 0.9644)

Figure 4.3 shows the contact time versus drop height for the drop test of futsal ball size four. From the graph, the R^2 was 0.9644. The relationships between the two variables have a 96% of variation in the data. This contact time was determined through the experiment of the drop test. As can be seen, the contact time increased with the increase in drop height. This is believed to occur due to the material of the futsal ball itself, which the transition of energy required more contact time between the ball and the steel plate. This graph pattern is in agreement with the result reported by another researcher. The contact time at 0.5 meter recorded 0.135 second while the maximum contact time at 1.5 meter with 0.15 second. From the literature, the shorter the contact time, the higher the impact force.

4.3 Drop Test (Simulations)

The simulation model of the futsal ball size four is set up in Solidworks 2015. A model of the futsal ball is shown in Figure 4.4. In the simulation, the ball drop is in the direction of gravity as a rigid body until it hits the rigid plane. It was assumed that there is no ball rotation.

In this study, the futsal ball is assumed as a linear isotropic material, and the friction was ignored. Young's Modulus, Density and Poisson's ratio are as shown in Table 3.4 in Chapter 3. The software solver for this analysis used was explicit time integration. The drop test simulation was run in three types of materials, which was generally used in the development of the futsal ball. The materials are butyl rubber, latex rubber, and natural rubber.

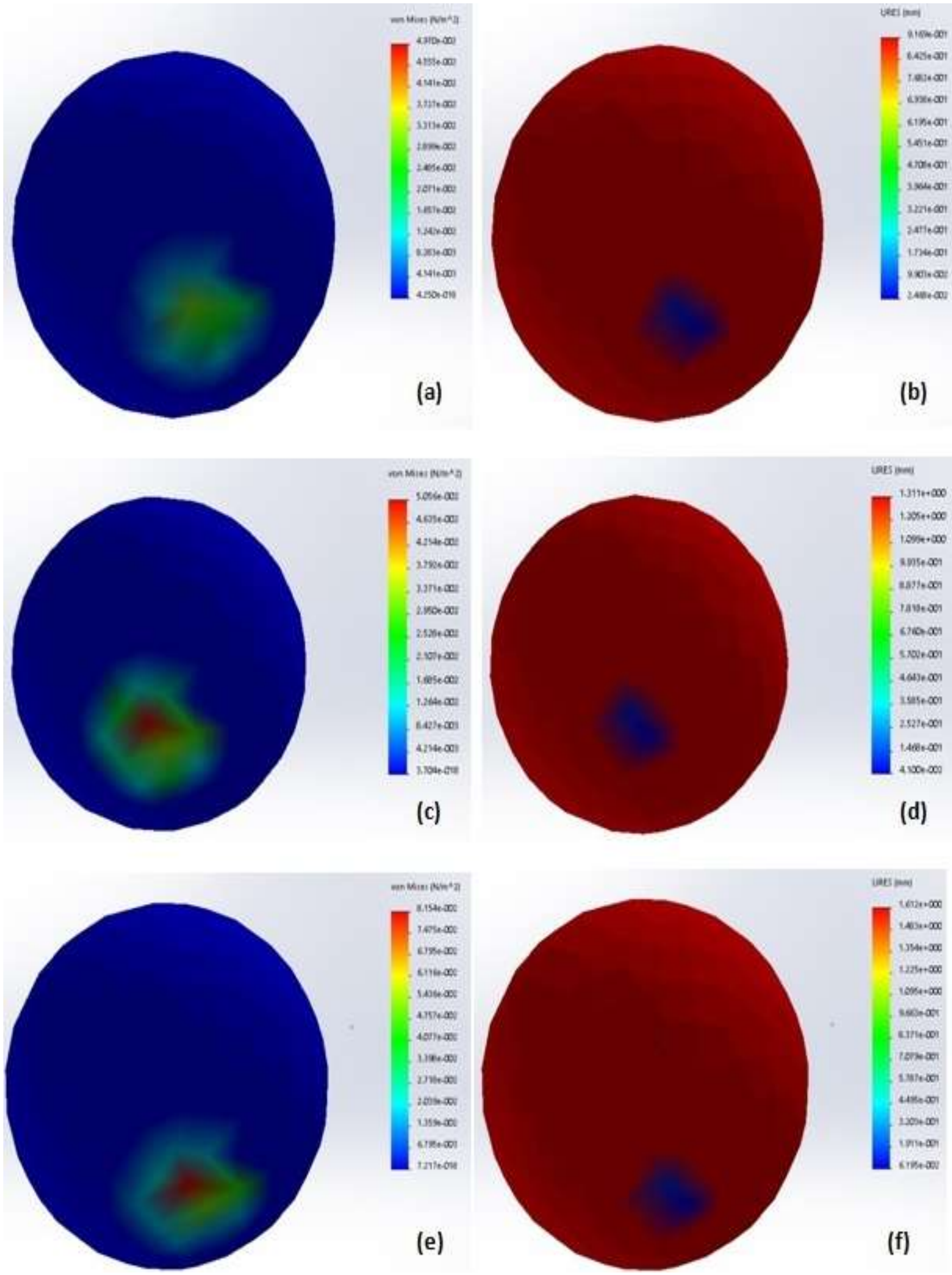


Figure 4.4: (a) - (b) Butyl simulation stress and displacement results for 0.5 meter, (c) - (d) Butyl simulation stress and displacement results for 1.0 meter and (e) - (f) Butyl simulation stress and displacement results for 1.5 meter

Figure 4.4 shows the stress and displacement image result in the drop test simulations for butyl rubber. As can been seen, the maximum stress and displacement are shown at the 1.5 meter drop height, that is 0.082 N/m^2 for the stress and 1.612 milimeter for the deformation of the ball. The increased stress and displacement is assumed to be due to the inelastic collision between the ball and the rigid surface.

Table 4.1 shows detail of the material, butyl rubber used for the simulation. Model type for the simulation is Linear Elastic Isotropic. Butyl rubber in this simulation is a material property 2 N/m^2 of elastic modulus, 0.5 Poisson's ratio and 920 kg/m^3 mass density.

Table 4.1: Details simulation data for butyl rubber size four ball

Name :	Butyl Rubber
Model Type :	Linear Elastic Isotropic
Elastic Modulus :	2 N/m^2
Poisson's Ration :	0.5
Mass Density :	920 kg/m^3

Butyl rubber is typically used in the development of sports equipment, such as in rugby ball, basketball, and netballs. In futsal balls, butyl rubber is used in the third part of futsal ball as the bladder's material. The butyl rubber is popularly used as a bladder as it provides a robust and airtight inner compartment. Other than that, butyls are impermeable material makes it used for the inner liner that holds the air in the tires.

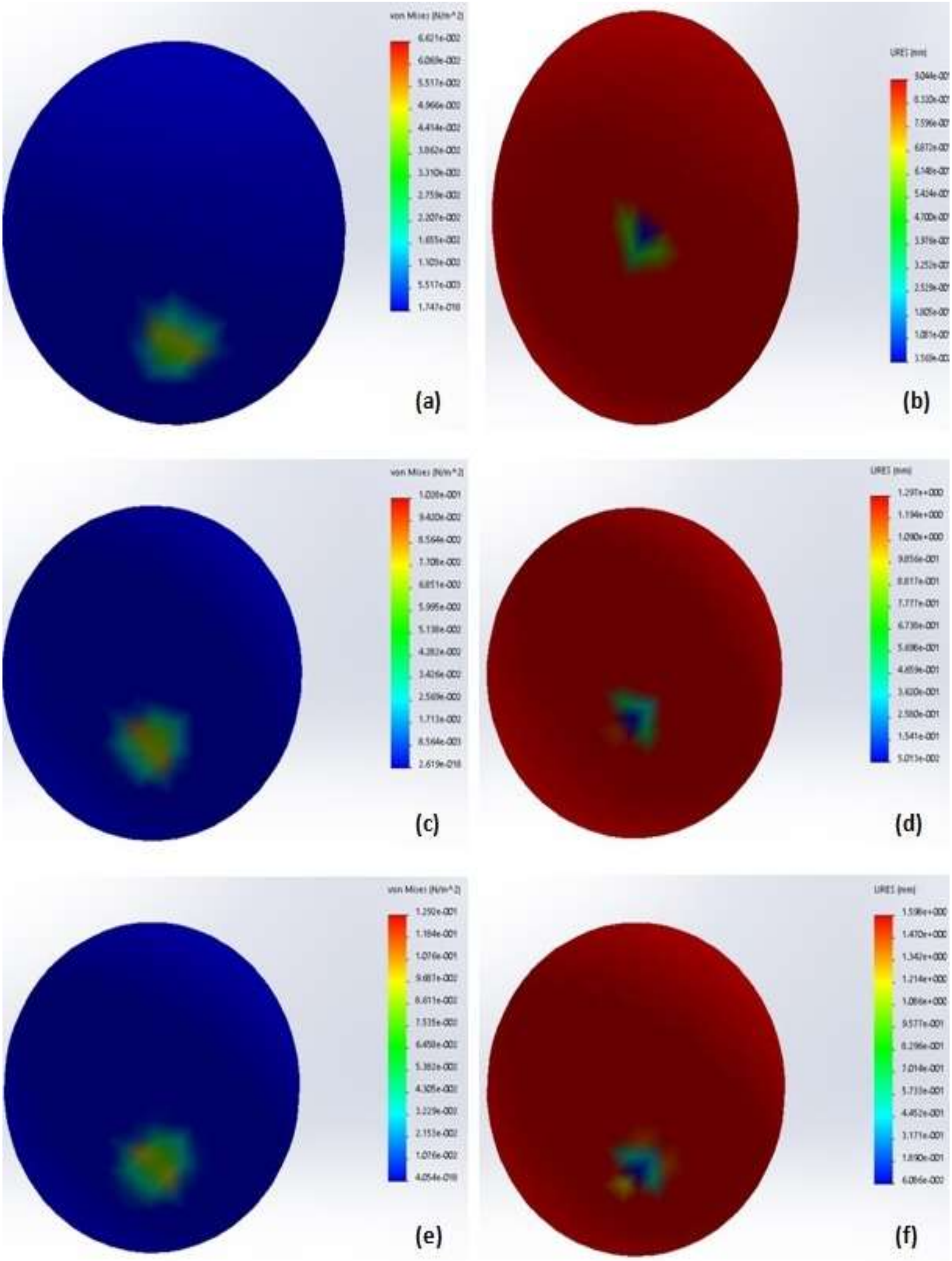


Figure 4.5: (a) - (b) Latex simulation stress and displacement results for 0.5 meter, (c) - (d) Latex simulation stress and displacement results for 1.0 meter and (e) - (f) Latex simulation stress and displacement results for 1.5 meter

Figure 4.5 shows the stress and simulation image results of the simulation for the latex rubber material. As can be seen, the stress and simulation for latex also increased as the drop height increase: The maximum stress 0.129 N/m^2 and the deformation at 1.598 milimeter at 1.5 meter.

Table 4.2 shows detail of the material, latex rubber used for the simulation. Model type for the simulation is Linear Elastic Isotropic. Latex rubber in this simulation is a material property 2.5 N/m^2 of elastic modulus, 0.5 Poisson's ratio and 940 kg/m^3 mass density.

Table 4.2: Details simulation data for latex rubber size four ball

Name :	Latex Rubber
Model Type :	Linear Elastic Isotropic
Elastic Modulus :	2.5 N/m^2
Poisson's Ration :	0.5
Mass Density :	940 kg/m^3

Apart from butyl rubber, latex rubber is used as bladders in futsal balls. Latex rubber has properties less deformation compare to butyl. Because of it, latex rubber bladder ball is more responsive and preferred materials in professional games.

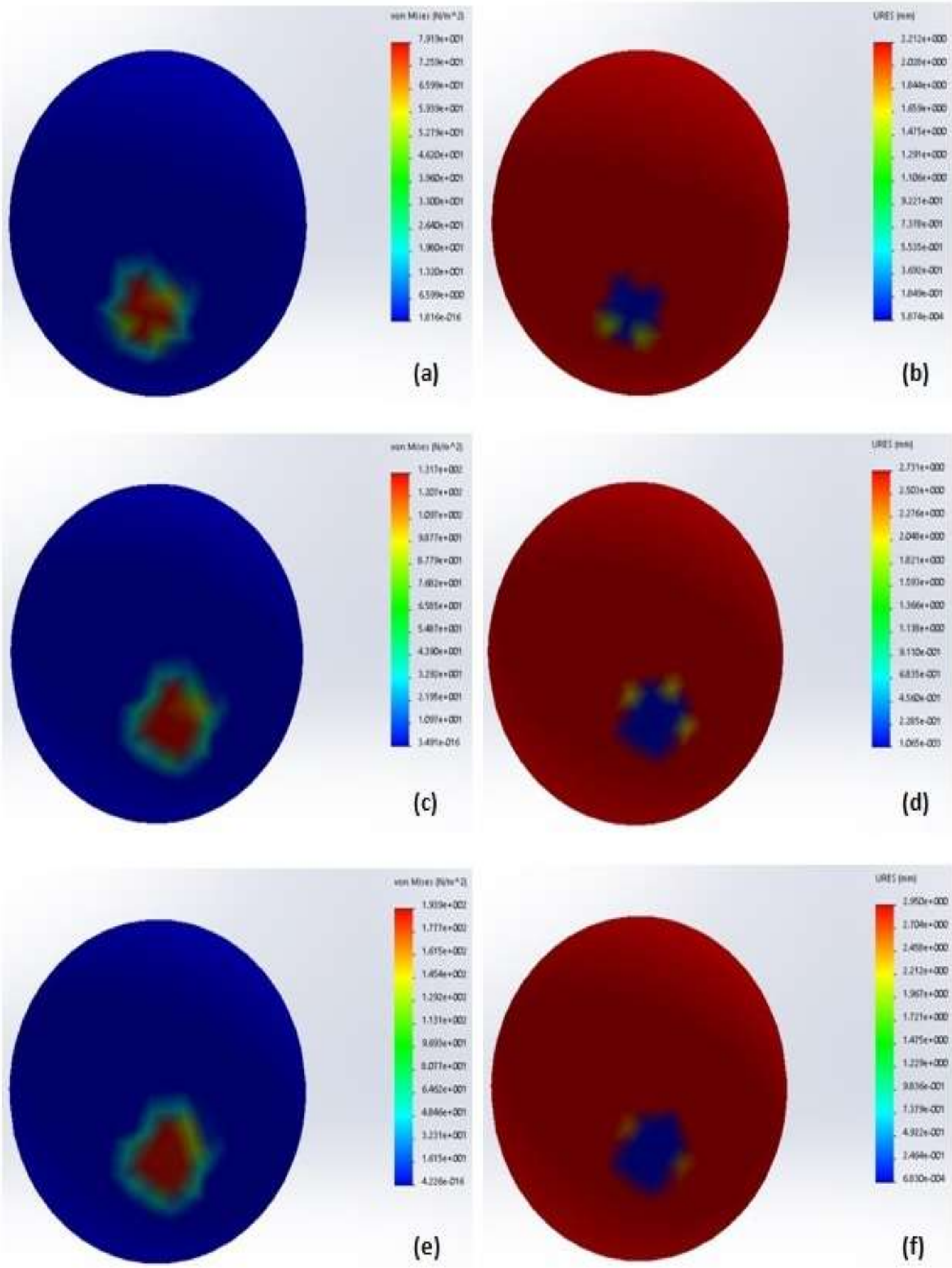


Figure 4.6: (a) - (b) Natural Rubber simulation stress and displacement results for 0.5 meter, (c) - (d) Natural Rubber simulation stress and displacement results for 1.0 meter and (e) - (f) Natural Rubber simulation stress and displacement results for 1.5 meter

Figure 4.6 shows the simulation result for stress and displacement for natural rubber. As can be seen, the stress and deformation of the ball increase with the increasing the drop height. The results obtained the same with both butyl and latex rubber. The maximum stress and deformation for natural rubber were recorded as 193.851 N/m^2 and 2.950 milimeter respectively.

The results from the natural rubber are the highest compared to butyl and latex rubber. The different results are assumed to be due to the properties of the natural rubber have a properties higher tensile strength compared to the butyl and latex.

Table 4.3 shows detail of the material, Natural rubber used for the simulation. Model type for the simulation is Linear Elastic Isotropic. Natural rubber in this simulation is a material properties 200 N/m^2 of elastic modulus, 0.46 Poisson's ratio and 1050 kg/m^3 mass density.

Table 4.3: Details simulation data for natural rubber size four ball

Name :	Natural Rubber
Model Type :	Linear Elastic Isotropic
Elastic Modulus :	200 N/m^2
Poisson's Ration :	0.46
Mass Density :	1050 kg/m^3

Figure 4.4 to Figure 4.6 show the simulation results from three types of rubbers. As can be considered from the three types of materials used in the simulation, natural rubber showed the highest stress and deformation. The 1.5 meter drop showed the highest stress and deformation for each type of materials. The results from the simulation showed the same pattern as the experiment results — the deformation increase as the drop height increase.

From the simulation, it proves that differences in ball materials gave different results even when they applied the same force. In reality, the responsive ball is the preferred ball material. If referring to the deformation and the stress, latex rubber is responsive.

The butyl is durable and retains air (fewer deformations). From the results, natural rubber is not suitable in terms of higher impact and stress in the use of ball impact with the head during heading.

4.4 Comparison of Experimental and Simulation Results

The Finite element model was in agreement with experimental data for a range of elasticity and the deformation. The marginal discrepancies between the two sets of data could be due to errors within the finite element model and the experimental data.

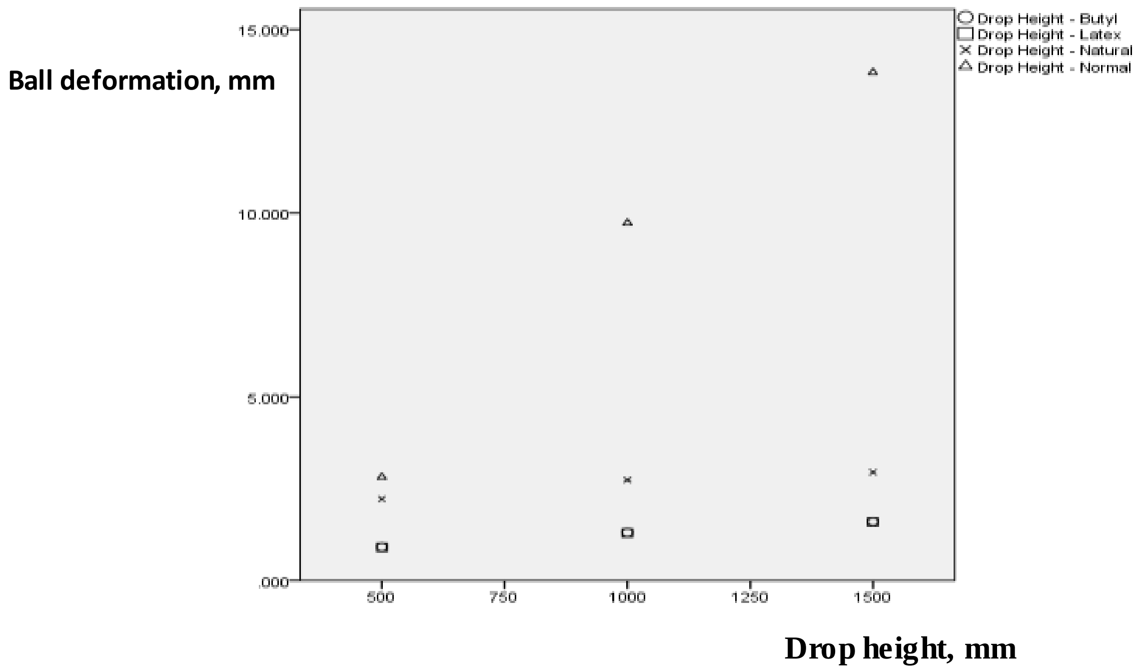


Figure 4.7: The graph drop height in mm versus deformation in mm for three types of materials

Figure 4.7 shows the graph of deformation of the futsal ball size four versus the drop height. Image of the graph shows the comparison between the normal deformation from a standard drop test and the deformation of simulation of three types of materials. As can been seen, the normal deformation from the experiment showed the increasing and highest value of deformation compared to simulation.

Table 4.4: The Pearson Correlation table between the drop heights to the deformation of the futsal ball

Correlations

		Drop Height	Butyl	Latex	Natural	Normal
Drop Height	Pearson Correlation	1	.997*	.997*	.972	.989
	Sig. (2-tailed)		.049	.049	.152	.093
	N	3	3	3	3	3
Butyl	Pearson Correlation	.997*	1	1.000**	.987	.998*
	Sig. (2-tailed)	.049		.000	.103	.044
	N	3	3	3	3	3
Latex	Pearson Correlation	.997*	1.000**	1	.987	.998*
	Sig. (2-tailed)	.049	.000		.103	.044
	N	3	3	3	3	3
Natural	Pearson Correlation	.972	.987	.987	1	.996
	Sig. (2-tailed)	.152	.103	.103		.059
	N	3	3	3	3	3
Normal	Pearson Correlation	.989	.998*	.998*	.996	1
	Sig. (2-tailed)	.093	.044	.044	.059	
	N	3	3	3	3	3

The Pearson Correlation was used in this analysis. This correlation coefficient used to measure the strength of the association between the two variables. Table 4.4 shows that the strength of association between the variables is very high. The correlation comparison is between the deformation of the ball to the drop height relationships.

From the drop test experiment, the normal deformation is shown the Pearson Correlation, $r = 0.989$, the correlation coefficient is significantly different from zero ($P < 0.011$).

From the simulation, the Pearson correlation by butyl and latex rubber material shows the highest and same correlation ($r = 0.997$). The correlation coefficient is very highly significantly different from zero ($P = 0.001$). The natural rubber shown the correlation ($r = 0.972$).

The Pearson correlation shows the positive linear relationship between the drop height to the deformation of the balls. It can be concluded that the drop height is affecting the deformation of the ball. The drop height (h) of the ball, affecting the difference in aspect of the velocities $\left(v_0 = a_g \times \sqrt{\frac{2 \cdot h}{a_g}}\right)$ and the force $\left(F = m a_g \boldsymbol{h}\right)$ of the ball. The difference hight, $\boldsymbol{h}$, results in a difference of velocities and the force during impact.

4.5 Discussion

In this study, the material assumed in the simulation was as butyl, latex and natural rubber. Finite element models of a futsal ball size four were developed to better understand the mechanics of the futsal ball during impact in general. Most specifically, they were needed to understand the mechanics of the futsal ball during impact and to validate some of the experimental data.

A Futsal ball is a complex object consisting of many nonlinear materials such as stitching, bladder and outer panel. Based on all the data analysis above, this present study can conclude that the material plays a vital role in the development of the futsal ball.

From the drop test experiment, the futsal ball size four underwent three different drop situations. From three different drop heights, it showed the same pattern as from other researchers, the higher drop height, the less value of COR. The 0.5 meter showed the maximum COR and the 1.5 meter showed less COR. The coefficient of restitution showed the effects on the elastic collision between the futsal ball and the hard target. The value of the COR is less than 1, (R = -0.914). Generally, it is shown that a large amount of kinetic energy was absorbed through the deformation.

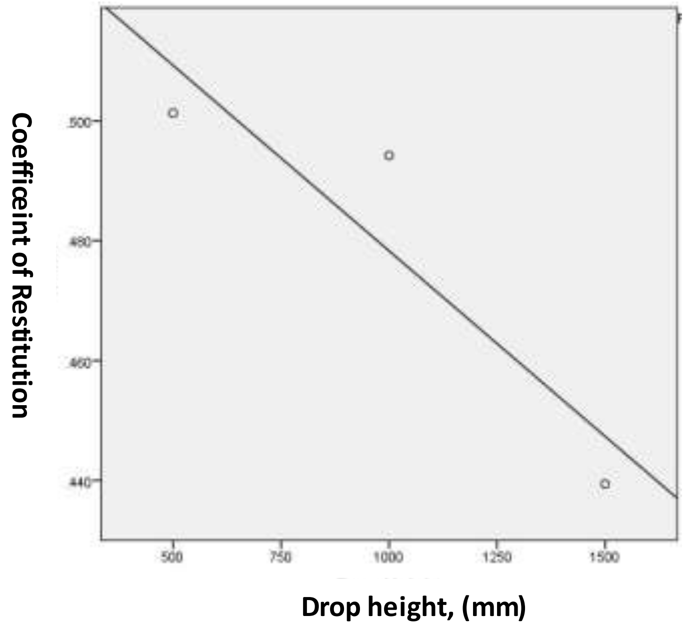


Figure 4.8: Graph COR versus Drop height, with Pierson's Correlation Between the variables, R = -0.914

During the impact, the ball initially deforms and squashes towards the inward point of the drop, then springs back to shape and pushes away from the steel plate. In order to get this situation, during the kicking, the ball is generally lighter. To accelerate the ball to high speed, one does not need to kick the ball very hard.

The dynamic problems, from the equation,

$$F_I(t) + F_D(t) + F_E(t) = R(t) \qquad \text{Equation 4.4}$$

The elastic force, $\mathbf{F_E(t)}$ equal to the external force $\mathbf{R(t)}$. Value of the coefficient or restitution showed that the elasticity of the futsal ball is directly proportional to the force applied. The force applied is maximum as the drop height increase.

The impact force of a falling object is given by using

$$F = ma_g h \qquad \text{Equation 4.5}$$

Where m = mass

a_g= gravitational acceleration (9.81 m/s^2)

h = dropped height (0.5, 1.0 and 1.5 meter)

From the 0.5 meter drop, the ball was dropped with the velocity 3.1320 m/s and the ball impact force was 1.6372 Newton. The maximum impact force was 5.018 Newton, were calculated from 1.5 meter, at the velocity, 5.425 m/s. The impact force increases as the dropped height increase. Results from experiment and simulation can be ascribed in the conservation of energy. The stress and deformation decrease as the drop height increase. The higher the drop height, the higher the deformation, and it is shown that during the deformation, the ball hits the hard target.

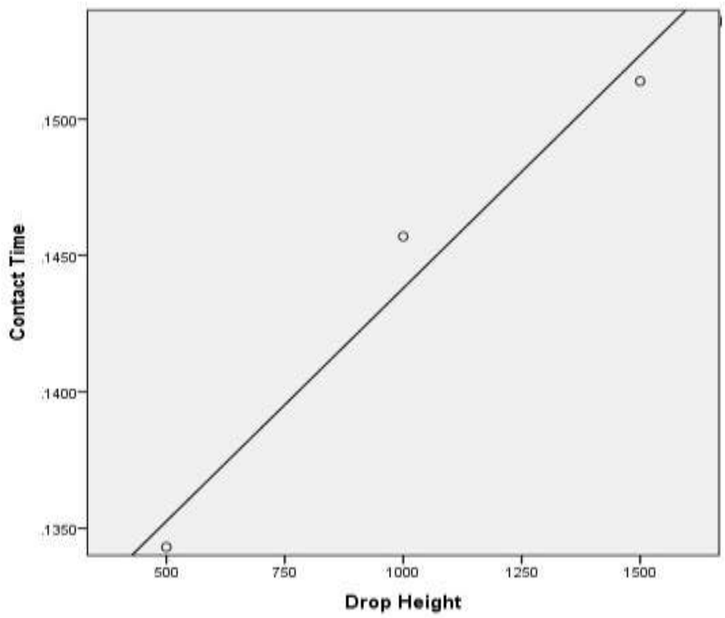


Figure 4.9: The contact time graph versus drop height, with Pierson's Correlation (R, = 0.982)

In this study, the dynamic properties of futsal ball dimension four have been investigated in this study through suggest of numerical simulations the usage of finite element analysis and experiments. According to Rodrigues et al. (2016) the chance of concussion is 4 to 22% for futsal ball heading, exactly at the forehead.

4.6 Summary

This chapter investigates the finite element model of futsal ball size four. The finite element model was in good agreement with experimental data for a range of elasticity and the deformation. The marginal discrepancies between the two sets of data could be due to errors within the finite element model and the experimental data.

Butyl, latex and natural rubber are customarily used in the development of the bladder of futsal ball. Butyl and latex, are popularly used in the futsal ball, as the advantages of these types of materials. Butyl is used as butyl bladder are durable and retain air very well. At the professional level, latex bladder football is mostly used, as the latex bladder ball is responsive.

From the simulation of the drop test, the deformation of the natural is higher compared to butyl and latex material. From the deformation results, it can be concluded that the natural rubber easily lost air compared to butyl and latex. Apart from that, natural rubber showed the maximum stress with 193.851 N/m^2 at the drop height 1.5 meter at velocity 5.425 m/s. From the simulation properties, natural rubber ran in the highest modulus elasticity at 200 N/m^2. It can be concluded that the impact resistance of materials decreases with an increase in the modulus of elasticity. Stiffer materials showed less impact on resistance.

In general, the futsal ball is developed in three main parts, that are; cover from polyurethane, inner lining from polyester, and the bladder from butyl and latex rubber. As the futsal ball bladders are filled with foam, the material of the bladders plays a vital role in the development of the futsal ball. Foam in futsal ball is used to limit the capability of bouncing.

Deformation increases, which leads to an increase in stress. The more an object is deformed, the more stored energy it has. From the simulation results, natural rubber showed the highest deformation and stress. The ball materials that have less deformation directly contribute less stress. It can be concluded that less deformation is better for the ball as the ball will cause repetitive head impact during the heading.

The method in this project can be applied to the different size of futsal ball, and this could be used to determine the influence of adjusting parameters such as mass and structural stiffness. The principle could also be applied to other sports equipment such as football or rugby ball.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Chapter Overview

The target of this study is to compare the experimental to simulation consequences on the effect of the futsal ball impact properties on three different heights. The study was conducted with 35 trials for every drop height (h = 0.5, 1.0 and 1.5 meter). The total number of tests carried out is was 105 trials.

5.2 Conclusion

The studied was performed to investigate the impact characteristics of futsal ball size four at three different heights and compared the experimental data with the simulation results in the usage of the SolidWorks Simulation software. The purpose of this research is to determine the results of the coefficient of restitution (COR), deformation (D) and the contact time (t) between the heights of the ball release.

In overall, this study has achieved the objectives of the research. The normal drop impact test was conducted, by employing a video camera to capture the impact properties and the motion sensor as the data collections. There also a design model of futsal ball size four and the simulation of the study was conducted for final data collection.

5.2.1 Impact Properties

The research objective one was achieved by determining the impact properties of futsal ball size four by conducting the standard drop test. The impact drop test was conducted to determine the dynamic properties of the futsal ball. The coefficient of restitution (COR), deformation, and contact time was determined by employing the video camera (up to 1000 fps) and the motion sensor (Sparco).

The height of the ball drops effects energy loss during the impact. From the resulting chapter four, it can be concluded that there is a statistically significant difference between the futsal ball size four drop height and the ball properties.

It was shown that increasing the drop height of the ball increases the force, deformation and the contact time of the ball. It has been stated that more energy was changed during the drop duration and that transforms the energy to energy of motion. As the COR decreased, the energy was increasing for that particular drop height.

5.2.2 3D Model of Futsal Ball Size Four

A 3D model of futsal ball size four was developed using the Solidworks software. The second objective of this study was achieved as the model of futsal completed modelled by Solidwork software. The secondary objectives were to design a 3D model of the futsal ball size four. The futsal ball size four was assumed as a hollow ball with thickness 3 milimeters and modelled in dodecahedron shape, which consists of 20 hexagons and 12 pentagons.

5.2.3 Impact Simulation of Drop Test

The final objective was achieved by conducting the simulation drop test using the SolidWorks Simulation. The third objective was to develop an impact modelling of futsal ball for dropping impact simulation. Three types of materials were used as simulation material for futsal ball was butyl, latex and natural rubber.

The types of ball materials play an important role in enhancing performance as well as to make the sports equipment as user-friendly as possible to avoid injury. From the simulation results, there is a difference between the futsal ball material properties and the drop height. Natural rubber showed the highest stress and deformation among the butyl and latex rubbers.

It has been shown that a finite element solid futsal ball model accurately predicts rebound characteristics for known incidents conditions. Furthermore, the model has also been used to explain these rebound characteristics regarding the physical behavior of the ball during impact. Based on these studies, butyl rubber has greater absorption because the estimation value of stress and deformation is the lowest compared to others.

5.3 Future Work

Based on the finding, the recommendation for future studies should include:

1. The surface of contact.

The coefficient of restitution and the deformation can be affected by the surface of the contact material different kinds of contact effects on the dynamic properties of the ball. Based on the previous study conducted by Haron et al. (2012), that concluded that the variations of COR between different sports balls are different by impact surface.

2. Ball characteristics

In this study, the only consideration was futsal ball size four. Balls for standard play normally range from their size. Size three are suited for eight years old and younger. For international standards such as the Olympics, size five is used — the repetition of heading tactics on a play or training is harmful to the athletes.

Referring to the previous study conducted by Shewchenko et al. (2005), it was determined that the effects of ball characteristics do impact the response to the head.
It concluded that the ball mass, pressure, and size gave different results on impact severity to the head and neck.

3. Temperature effect

Based on a previous study conducted by Allen et al. (2012) that determined the effect of temperature change on golf ball dynamics, COR, impact duration, and deformation increased with the temperature. From that study, it is assumed that the temperature affects the dynamic properties of the ball during the impact. The future recommendation, does the temperature effects the characteristic of the ball during the trajectory movements.

In summary, the heading would possibly not be a necessary movement to hit the ball all through a futsal game. However, gamers are uncovered to a higher risk of suffering from MTBI due to frequent collisions between the players' foreheads and the ball. Hence, it is encouraged that the gamers put on protective headbands in order to reduce the effect at some point of heading and prevent the occurrence of MTBI in the long term.

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APPENDIX

Publications

Halley Pata Anak Alban Dattu, F., Tarmizi Syed Shazali, S., Andrew-Munot, M., Aizuddin Abang Mohamad Mohtar, A. M., & Hisyam Bin Noor Mohamed, N. (2018). Simulation Study of a Futsal Ball Deformation in Normal Impact Using Finite Element Method. *International Journal of Modeling and Optimization*, *8*(3), 188–192.

Syed Shazali S.T, Alban Dattu F.H.P, Aizuddin A.M, Andrew-Munot M., and Noor Mohamed N.H. (2018). Influence of Drop Height on the Impact Characteristic of Futsal Ball Size 4. *11th International Unimas STEM Engineering Conference 2018.*

Award

Bronze Award on Innovation Technology Expo (InTEX 18).

Halley Pata Anak Alban Dattu, F., Tarmizi Syed Shazali, S., Andrew-Munot, M., Aizuddin Abang Mohamad Mohtar, A. M., & Hisyam Bin Noor Mohamed, N. (2018). Simulation and Modelling of a Futsal Ball size 4 and Free Fall of Impact Test.