ANALYSIS OF LIGAMENT BEHAVIOUR FOR HEALTHY HUMAN LEG WITH OR WITHOUT KNEEPAD AFTER KICKING THE BALL

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To all family members,

I will always love you till the end of the time. Thank you for your support and blessing.

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ABSTRACT

Ligament is tough bands of fibrous tissues that connect between two bones. Those bones are the tibia and femur bones. The knee structure is including the femur (thighbone), tibia (shinbone), ligament, meniscus, articular cartilage, tendon and patella (kneecap). The anterior cruciate ligament (ACL) connects the femur to the tibia at the center of the knee. It limits rotation and the forward motion of the tibia. The ACL injury was found to be the highest among others ligament. Running and kicking is the activities that frequently can cause the ACL injury. In this study, a three-dimensional finite element model of the human ACL was developed and the simulation of passive knee flexion was performed. The objective for this study is to investigate the behaviour of the ACL effect when using knee pad during the kicking activities in soccer game. The numerical modeling of passive knee flexion was performed, with and without applying the stress on the ACL. The analysis will consist of analysis with the kneepad and analysis the knee without the knee pad. Both of the analysis involved in knee posturer angles. The angles are 0°, 45°, 90° and 155° of knee flexion. The results show that 90° flexion give highest stress value among other knee flexion. One possible explanation is that, the ligaments already reach its final stages for twisting. After this stage, the ligament will not twisting but it will start to bend. The ligament will bend until it reaches it bending limit.

ABSTRAK

Ligamen merupakan salah satu tisu kompleks yang menghubungkan di antara dua jenis tulang iaitu tulang “Tibia” dan tulang “Femur”. Struktur lutut terdiri daripada tulang “Femur” (tulang peha), tulang “Tibia” (tulang betis), ligamen, meniskus, tulang rawan, tendon dan patella (tempurung lutut). “Anterior Cruciate Ligament” (ACL) menghubungkan tulang “Femur” ke tulang “Tibia” di tengah-tengah lutut. ACL mengawal had pergerakan ke hadapan dan juga putaran “Tibia”. Kecederaan ACL mencatatkan kecederaan paling tinggi berbanding ligamen yang lain. Antara aktiviti yang kerap berlaku kecederaan kepada ACL adalah disebabkan oleh aktiviti berlari dan juga menendang. Untuk kajian ini, model 3D untuk ligamen telah dihasilkan dan analisis telah dijalankan. Objektif kajian ini, adalah untuk mengkaji kesan tindak balas ACL apabila memakai pad lutut atau tidak memakai semasa melakukan aktiviti menendang dalam permainan bola sepak. Untuk analisis kajian ini, ia merangkumi analisis apabila kaki memakai pad lutut dan juga analisis apabila kaki tidak memakai pad lutut. Kedua-dua analisis ini merangkumi beberapa sudut kaki, antaranya 0^{o}, 45^{o}, 90^{o} dan akhir sekali ialah 155^{o}. Daripada analisis yang telah dijalankan, ia menunjukkan bahawa semasa kedudukan kaki pada sudut 90^{o}, ia mencatatkan nilai tekanan yang paling maksimum jika di bandingkan di antara sudut yang lain. Ini kerana pada masa ini, ACL sudah mencapai tahap maksimum untuk berputar. Selepas fasa ini, ACL akan berhenti berputar pada paksi, dan mula untuk membengkok sehingga ACL mencapai tahap maksimum untuk membengkok.

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LIST OF SYMBOLS

P	Pressure
F	Force
A	Area
m	Mass
g	Gravity

LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
FEM	Finite Element Method

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CHAPTER 1

INTRODUCTION

This chapter will describe about the background, problem statement, objectives and scope of the study. From the background of the study, it comes out the problem statement and from the problem statement; the purpose of this study can be identified. This study will be based on the objective that have been determined and is limited by the scopes.

1.1 BACKGROUND OF STUDY

Ligament is tough bands of fibrous tissues that connect between two bones. That bone is the tibia bones and the femur bones. Knee structure is including the femur bones (thighbone), tibia bones (shinbone), ligament, meniscus, articular cartilage, tendon and patella (kneecap). For knee there are 4 major ligament parts which are the tibia collateral ligament, fibular collateral ligament, anterior cruciate ligament and posterior cruciate ligament. All of these ligaments are used to connect the bones on the knee which is the tibia bones and the femur bones. All of this ligament, they have their own function. The lateral collateral ligament runs on the outside of the knee. It limits sideways motion. The medial collateral ligament runs down the inside of knee joint. It connects the femur to the tibia and limits the sideways motion of the knee. The articular cartilage lines the bones, cushioning your joint. The meniscus is cartilage that absorbs shock in your joint. The posterior cruciate ligament also connects the femur and tibia. It limits backward motion of the tibia. The anterior cruciate ligament connects the femur to the tibia in the center of the knee. It limits rotation and the forward motion if the tibia.

More than any other joint in the body, the knee joint depends on its ligamentous structures to maintain its integrity and act as primary stabilizers for guiding movements. The anterior cruciate ligament (ACL) provides the primary restraint for anterior tibia translation and valgus-valgus motion in full extension and rotation. The ACL is the most commonly injured ligament of the body especially during sport activities and motor vehicle accidents and therefore the biomechanics of the ACL is of interest. Based on the anatomy and tensioning patterns of this ligament during knee flexion and extension, the ACL can be divided into two bundles, an anteromedial (AM) bundle and a posterolateral (PL) bundle. ACL injury was found to be the highest among others ligament. Running and kicking is the activities that frequently can cause the ACL injury. When decelerating in running, the hamstrings act eccentrically to slow extension at the knee, and the quadriceps act eccentrically to control the lowering of body weight when athletes approach a stop. In kicking activation follows 'the soccer paradox', which means that flexor activity is dominant during extension and extensor activity dominates during flexion. In fact, quadriceps activity is greatest during the loading phase when it is antagonistic to the movement. On the other hand, hamstrings are most active during the forward swing when they are antagonistic to the movement.

1.2 PROBLEM STATEMENT

Soccer is the most popular sport in all over the world. Its popularity has grown through the years. As reported in 1982, this game has been played by at least 40 million people in 150 countries. By 1992 this number of played had grown to about 200 million. In Italy, there are about 1,200,000 affiliated players and 3,000 of them are professionals (Volpi, 2000). Soccer is responsible for about 50% to 60% of all the sport-related injuries (Nilsson, 1978).

The human anterior cruciate ligament (ACL) plays an essential role in maintaining knee stability in multiple directions and is one of the most frequently injured ligaments of the knee, especially during sport activities (Daniel *et al*., 1994;

Griffin *et al*., 2000, Speer *et al*., 1995). Based on the anatomy and tensioning patterns of this ligament during knee flexion and extension, the ACL can be divided into two bundles, an anteromedial (AM) bundle and a posterolateral (PL) bundle (Girgis *et al*., 1975).

1.3 RESEARCH OBJECTIVES

The objective of this study is to develop the three dimensional (3D) of an anterior cruciate ligament (ACL) behavior and to investigate the ACL effect for healthy human leg with and without the knee pad during kicking the ball.

1.4 SCOPE OF RESEARCH

In order to achieve the above mentioned objective, the following scope has been drawn:

i. Limit on the three dimensional model of ligament only.
ii. Using only two types of kicking which is the side kick and the instep kick.
iii. For side kick the velocity use are 14.95m/s, 17.4m/s and 19.91m/s. (source experimental for kicking)
iv. For instep kick the velocity use are 17.1m/s, 19.24m/s and 24.8m/s. (source experimental for kicking)
v. Force distribution from the soccer player equal to for side kick 165N, 191N and 218N, for instep kick 256N, 288N and 371N.
vi. Using the stress distribution with the leg condition of 0 degree, 45 degree and 90 degree and 155 degree only.
vii. Fixed body weight is 570N.
viii. Player age around 22 years old.

1.5 ORGANIZATION OF THE THESIS

This final year project report is divided into five chapters. In which the chapter 1 is the introduction part, chapter 2 is the literature review part, chapter 3 is the methodology part, chapter 4 is the result and discussion part, and chapter 5 is the conclusion part.

In the chapter 1, it introduces the background of the study, and in addition, it explain a simple important details in this study of material of the knee pad, and several important information about the knee pad and also the ligament, some others factors should be considered, problems statement that is related to the topic study, the objectives, scope of the study, the expected results and the report arrangement.

In the chapter 2 it presents the information of the ligament which is the anterior crucial ligament (ACL), the ACL injury, importance of the knee pad for the football player, kneepad problems nowadays, material selection for the kneepad, designing process, and the comparison of muscle reaction of a person that are wearing a knee pad and the person who are not wearing

In the chapter 3 includes the all proposed design where the physical parameter, consideration, and defect will be considered. This chapter will describe the detail of the methodology used in this study, by modeling and simulation the ACL. There are two sets of analysis which is the knee analysis using the knee pad and the other one is the knee analysis without the knee pad. The dimension of the ACL and the knee used in modeling was referred to the previous study. Besides, the parameters used to setup the simulation of the fluid and structure was based on the literature. The whole simulation was performed by using AUTODESK software. During the diastolic and systolic setup, the simulation was performed in a time period of 1 second and independent parameters like the flow and pressure variables was applied to the human knee.

In the chapter 4, in this chapter, the simulation result obtained from the analysis on the knee joints are presented and discussed. Both of the knee sets are simulate using same force distribution which is 474N, 768N, 909N and 977N. The finite element method software is used to simulate the knee joint. The result in form of graph stress values against strain was plotted. The comparison between both sets also has been decided. As for the validation, the comparison between calculation value and simulation value has been made.

Chapter 5 presents the conclusion being made from experiment in order to classify the best fiber material among all of the fiber used and the also the recommendations that can be suggested for future benefits.

CHARTER 2

LITERATURE REVIEW

In this chapter, the basic knowledge which related to the human knee will be described. A simple explanation and introduction to the ligament especially the anterior crucial ligament (ACL) have been presented. Besides, the common ACL disease that related with the sport activities will be defined. The treatments for the ACL disease also will be introduced. Moreover, fluid flow theory and the fundamental engineering theories also will be described during simulation in this study. The simulation could be explained by using certain of the formulae and equations. Lastly, some journals regarding to simulation study which are highly related to this study will be summarized. The idea and dimension used to applying in designing the ACL have been referred back to the previous study.

2.1 THE LIGAMENT CHARACTERISTICS

Ligament is used as the connection between the two bones. The bones are tibia bone and the femur bone. Ligament is the sensitive tissues that can easy to occur decease in daily life. There is 4 major part of ligament in knee of human. The first part is the tibia collateral ligament part. MCL is a wide, thick band of tissue that runs down the inner part of the knee from the thighbone (femur) to a point on the shinbone (tibia) about four to six inches from the knee. The MCL's main function is to prevent the leg from extending too far inward, but it also helps keep the knee stable and allows it to rotate.

The second part is the fibular collateral ligament part. The fibular collateral ligament or lateral collateral ligament is a thin band of tissue running along the outside of the knee. It connects the thighbone (femur) to the fibula, which is the small bone of the lower leg that turns down the side of the knee and connects to the ankle. Like the medial collateral ligament, the lateral collateral ligament's main function is to keep the knee stable as it moves through its full arc of motion. The third part is the anterior cruciate ligament part.

The anterior cruciate ligament runs diagonally in the middle of the knee. It prevents the tibia from sliding out in front of the femur, as well as provides rotational stability to the knee. The last part is the posterior cruciate ligament. It connects the posterior intercondylar area of the tibia to the medial condyle of the femur. This configuration allows the PCL to resist forces pushing the tibia posteriorly relative to the femur.

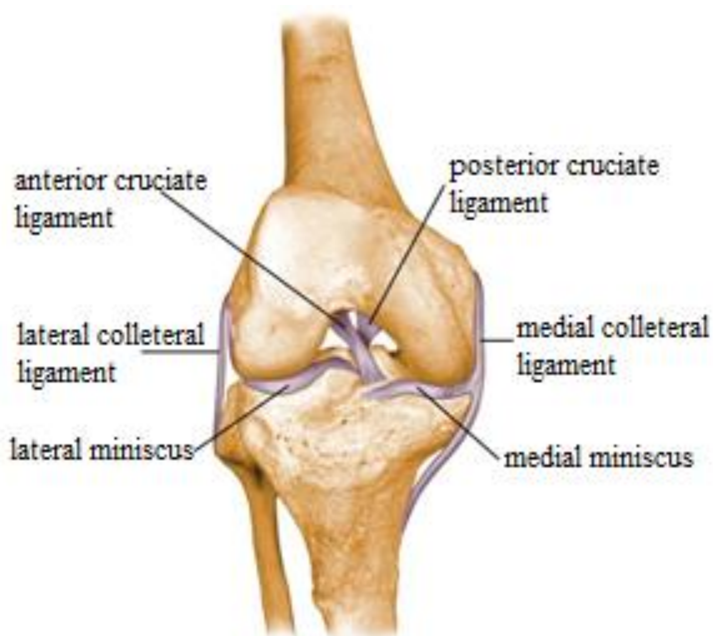


Figure 2.1: The Knee Structure

(Source: Calmbach, 2003)

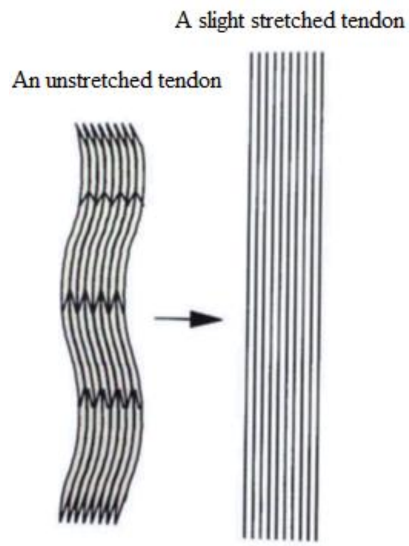


Figure 2.2: Structure of un-stretched tendon and slightly stretched tendon

(Source: Hauser, 2011)

2.1.1 Tensile Response Curve

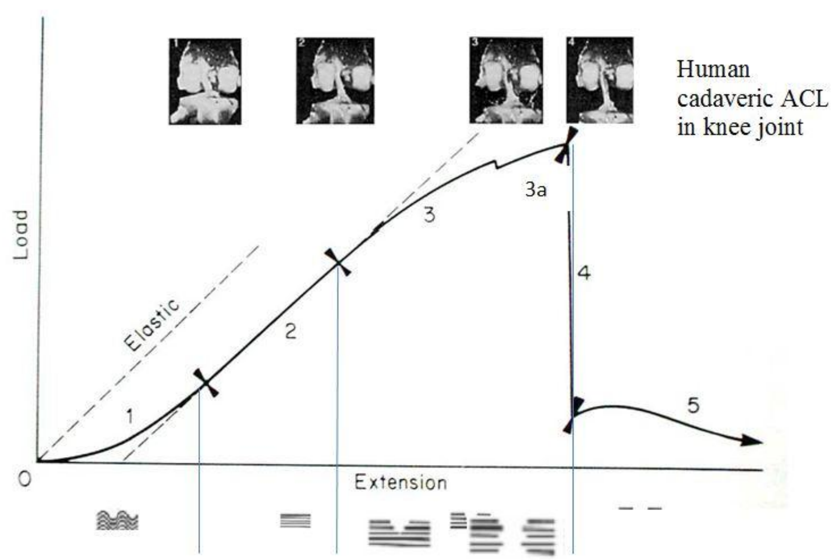


Figure 2.3: Mechanical Behavior

(Source: Hauser, 2011)

Table 2.2: Curve description

Region	Description
Region 1 "toe"	Crimp: low stiffness; change in slope as collagen fibers straighten; ligaments become more stiff as more fibers are recruited
Region 2	Linear region: slope = stiffness/elastic modulus Elastic: higher stiffness
Region 3	Less linear behavior; deformation is permanent (tearing, stretch); area of micro-failure; Ultimate load: where failure occurs (N)
Region 3a	Energy absorbed to failure: area under the curve (Nmm)
Region 4	Ligament ruptures
Region 5	Ligament may appear intact; Fibers to slide under low loads

2.2 ANTERIOR CRUCIATE LIGAMENT

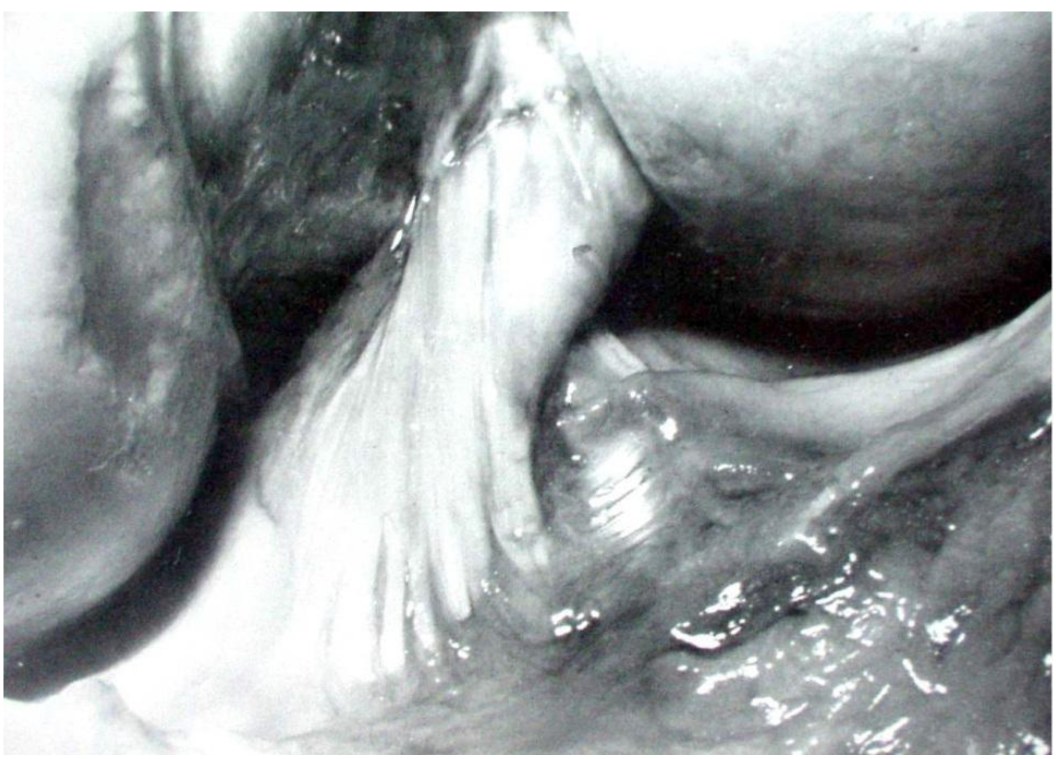


Figure 2.4: Anterior Cruciate Ligament

The anterior cruciate ligament is the smallest of the four main ligaments in the knee. Despite its size, it is the most important of the four in keeping your leg stable when you twist your body. It connects the thighbone (femur) to the largest shinbone (tibia) at the centre of your knee. Without the ACL, knee would wobble and move around when you twist your body. When the shinbone and thighbone rotate too far in opposite directions or when the knee is bent in the wrong direction the ACL can be torn or sprained. An ACL injury is a sprain, in which the ligament is torn or stretched beyond its normal range. In almost all cases, when the ACL is torn, it's almost always due to at least one of the following patterns of injury:

i. A sudden stop, twist, pivot or change in direction at the knee joint. These knee movements are a routine part of football, basketball, soccer, rugby, gymnastics and skiing. For this reason, athletes who participate in these sports have an especially high risk of ACL tears.
ii. Extreme hyperextension of the knee. Sometimes, during athletic jumps and landings, the knee straightens out more than it should and extends beyond its normal range of motion, causing an ACL tear. This type of ACL injury often occurs because of a missed dismount in gymnastics or an awkward landing in basketball.
iii. Direct contact. The ACL may be injured during contact sports, usually during direct impact to the outside of the knee or lower leg. Examples are a sideways football tackle, a misdirected soccer kick that strikes the knee or a sliding tackle in soccer.

Often when the anterior cruciate ligament tears, you will have damage to other ligaments most often the medial collateral ligament or the cartilage of the knee.

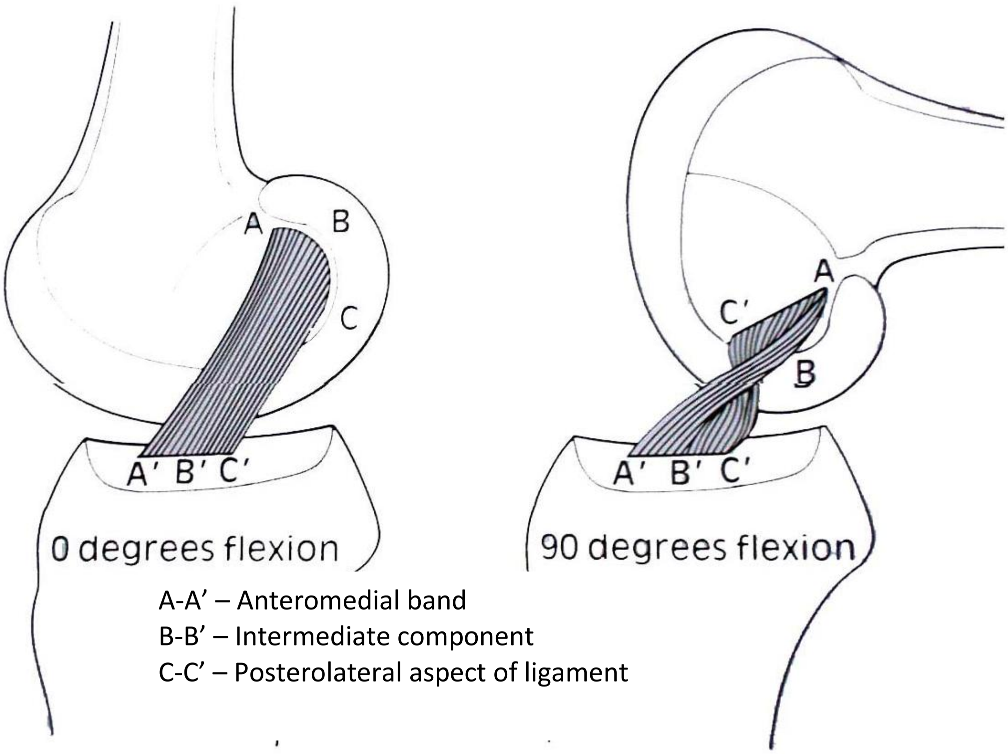


Figure 2.5: ACL Flexion

(Source: Zemirline, 2009)

Like other types of sprains, ACL injuries are classified by the following grading system:

i. Grade I. A mild injury that causes only microscopic tears in the ACL. Although these tiny tears may stretch the ligament out of shape, they do not affect the overall ability of the knee joint to support your weight.
ii. Grade II. A moderate injury in which the ACL is partially torn. The knee can be somewhat unstable and can "give way" periodically when you stand or walk.
iii. Grade III. A severe injury in which the ACL is completely torn through and the knee feels very unstable.

Overall, most ACL injuries are severe Grade IIIs, with only 10% to 28% being either Grade I or Grade II. Currently, between 100,000 and 250,000 ACL injuries occur each year in the United States, affecting approximately 1 out of every 3,000 Americans. Although most of these injuries are related to athletic activities, especially contact sports, about 75% occur without any direct contact with another player (Daniel *et al.*, 1994; Griffin *et al*., 2000 and Speer *et al*., 1995).

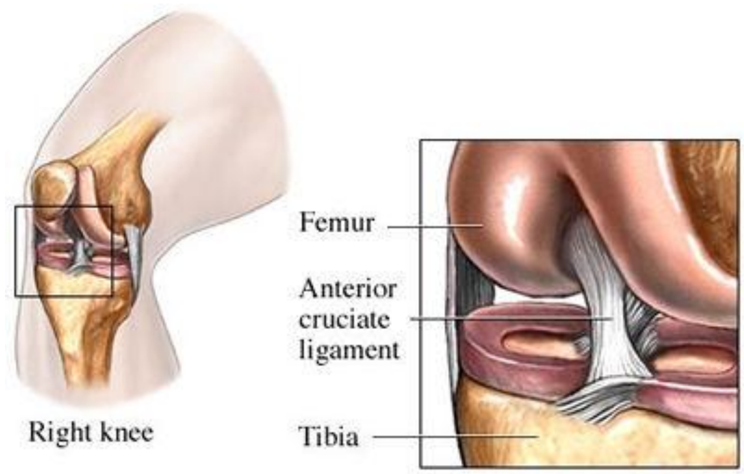


Figure 2.6: Anterior Cruciate Ligament

2.2.1 Symptoms of the ACL Injuries

If you tear your anterior cruciate ligament, you may have the sensation of your knee giving out or buckling. You may even hear a popping sound. Your knee joint will start to swell. This happens because the small blood vessels in the ligament also tear and leak blood into the joint. The pain resulting from a torn anterior cruciate ligament varies widely. The anterior cruciate ligament itself has no pain receptors. But the movement that causes the ligament to tear often causes damage to other parts of the knee that do have pain receptors. Some people are unable to walk. Others may feel they can play through the injury. Your knee often feels as though it will give way or easily bend backward.

After an acute injury, you will almost always have to stop the activity you are doing, but you may be able to walk. Other health problems can cause symptoms like those of an ACL injury. They include a bone break or injuries to the knee cushions (menisci) or to other ligaments in the knee.

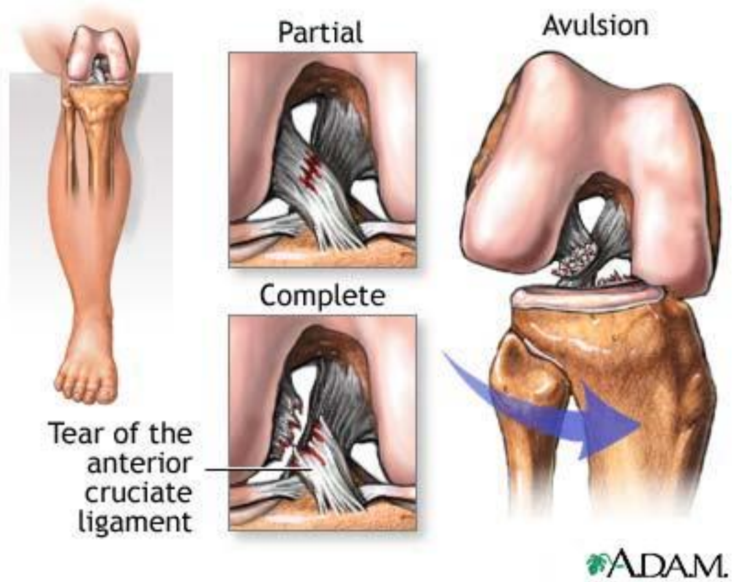


Figure 2.7: Tear of the Anterior Cruciate Ligament

2.2.2 ACL Surgery

Figure 2.8: The middle third of the patellar tendon has been used to make a new ACL (running from upper left to lower right, in front of the PCL).

The middle third of the patellar tendon has been used to make a new ACL (running from upper left to lower right, in front of the PCL). Surgical treatment of a torn ACL involves making a new ligament rather than trying to sew it back together, which is usually not successful. There are many ways to make a new ACL, or reconstruct the ACL. All of the methods involve using grafts or tissue from the patient or from a cadaver. The most popular grafts from the patient include using the middle of the patellar tendon or using the hamstring tendons. A variety of graft options from cadavers exist as well. Each graft option has its own risks and benefits, and a thorough discussion of the different grafts with the surgeon is critical.

The procedure is usually performed as an outpatient. The surgery is done mainly through the scope with the exception of taking the graft. The surgeon will look throughout the knee to evaluate for injury to other structures, such as the meniscus and articular cartilage and usually treat injuries found at the same time. The patient will often wake up from the surgery with brace as well as a device to allow cold water to flow around the knee. How much weight the patient can put on the leg depends on the status of other structures in the knee, especially the meniscus, as well as the preference of the surgeon.

2.3 RELATION BETWEEN ACL INJURIES AND SPORT

Soccer is the most popular sport in all over the world. Its popularity has grown through the years. As reported in FIFA 1982, this game has been played by at least 40 million people in 150 countries. By FIFA news 1992 this number of played had grown to about 200 million. In Italy, there are about 1,200,000 affiliated players and 3,000 of them are professionals (Volpi, 2000). Soccer is responsible for about 50% to 60% of all the sport-related injuries (Nilsson, Roass., 1978). Ligament injuries to knee and ankle joint represent the most common injury in several studies. Followed by muscle strains, muscle contusions or tendonitis depending on the study considered (Eriksson, Svensson, 1996).

Figure 2.9: Running Activities

Football is considered a contact sport, and it puts many demands on the technical and tactical skills of the individual player. Because of the characteristics of football, injuries must be expected (Ekblom, 1986). Football injuries, in general, are all types of physical damage to the body occurring in relation to football (Inklaar, 1994). Football injury incidence is mostly expressed as the number of new football injuries per 1000 hours of exposure in football (Backous, Friedl, Smith, *et al*., 1988). Risks may vary with position played or intensity and nature of activity during practice or games.

Various studies of the incidence of football injuries present different classifications of football injuries. Differences in classification could at least partly explain the differences in incidences found. Up until now, the most common way to classify injury and injury severity has been through (Inklaar, 1994).

i. Anatomical tissue diagnosis,
ii. Sporting time lost,
iii. Working time lost (social and financial consequences)
iv. Insurance claims
v. Medical treatment

ACL (anterior cruciate ligament) injuries of the knee are no longer seen only in adults. More and more teenage athletes are showing up in the emergency rooms with torn ACLs, and a large percentage of those injured are young female athletes (Folksam Insurance Company, 1994). The ACL, along with the PCL (posterior cruciate ligament) is one of the major ligaments that help stabilize the knee joint. The ACL is most often stretched, or torn by a sudden twisting motion while the feet remain planted (Daniel *et al*., 1994; Griffin *et al*., 2000). The majority of ACL injuries occur when an athlete misses a landing from a jump, pivots quickly while changing direction, or decelerates abruptly. These movements may cause the ACL to stretch to the point of tearing.

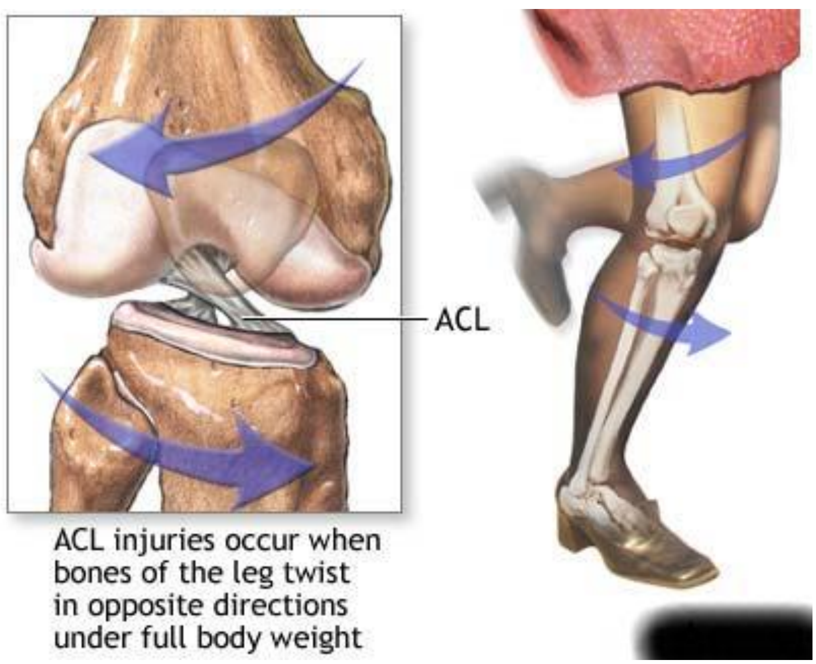


Figure 2.10: ACL Injuries

Figure 2.11: Kicking Activities

However, teens who participate in ACL prevention programs may greatly reduce their risk of an injury. These prevention programs are becoming more popular in youth sports and generally include exercises to help strengthen muscles and improve faulty movement patterns in teens. Multiple studies have demonstrated the effectiveness of ACL injury prevention programs.

There are a growing number of ACL injuries in young athletes who play sports such as soccer, basketball and volleyball (Ekstrand, Gitlquist, Liljedahl, 1983). Physicians speculate that part of the reason for the increase in ACL injuries may be related to the year-round sports training that many teens are doing (Speer *et al*., 1995). Playing sports constantly with no time off, playing multiple sports or playing field and court sports that emphasize quick starts, stops, and pivots makes teen athletes more susceptible to ACL tears. The risk is particularly high among athletes who play soccer, football, volleyball, or basketball.

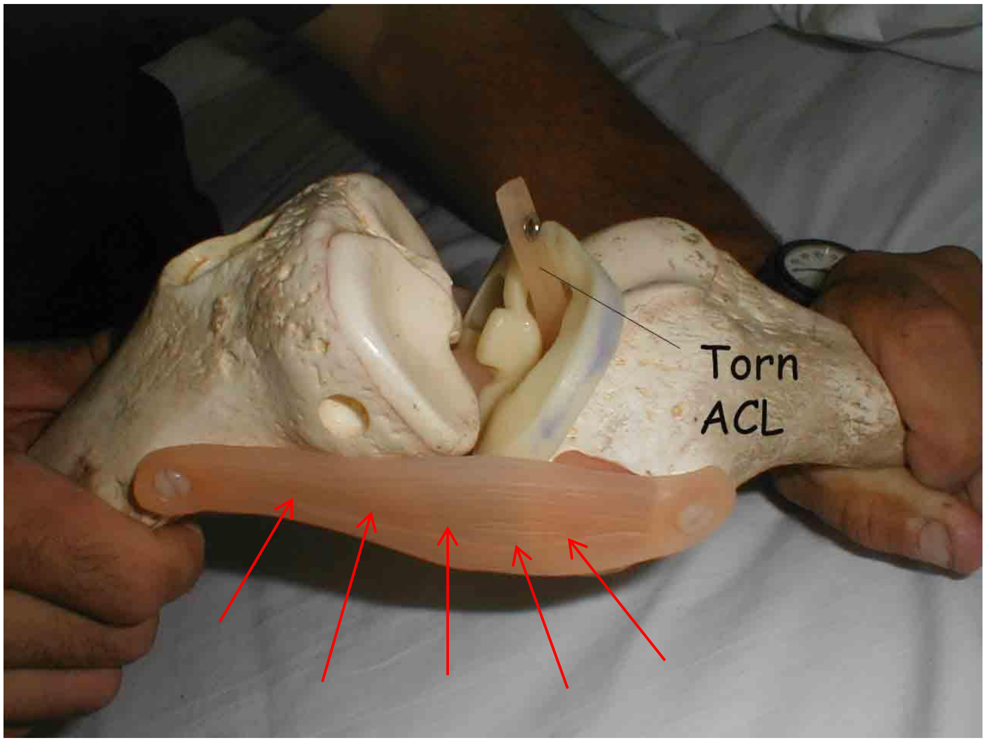


Figure 2.12: ACL Torn

Figure 2.13: MRI Film

These prevention programs are made up of training drills that emphasize balance, power and agility. Plyometric exercises and balance drills help improve neuromuscular conditioning and reaction time and may decrease the risk of ACL injury. Many coaches use an ACL conditioning program, especially for their female players, as a basic part of sports practice. These programs should include the following phases:

i. Warm Up

Warming up and cooling down are a crucial part of a training program. The purpose of the warm-up section is to allow the athlete to prepare for activity. By warming up your muscles first, you greatly reduce the risk of injury.

ii. Stretching

The warm up before stretching is very important to decreasing risk of injury. The following exercises help improve range of motion, reduce stiffness, reduce post-exercise soreness, reduce the risk of injury and improve overall mobility and performance.

iii. Strengthening

The strengthening phase of the program focuses on increasing leg strength. This will lead to increased leg strength and a more stable knee joint. Technique is everything; close attention must be paid to the performance of these exercises in order to avoid injury.

iv. Plyometric

Many athletes and trainers use plyometric jumping exercises to build power and speed, improve coordination and agility and effectively improve sports performance. It's also important to recognize that these are high risk exercises and if performed incorrectly or performed without a solid base of training, plyometric can increase the risk of injury.

v. Agility Drills

Agility skill exercises are designed to improve the power and strength in the muscles.

vi. Cool Down

Cooling down is essential to the program and shouldn't be skipped. It allows the muscles that have been working hard throughout the training session to elongate and deters the onset of muscle soreness.

2.4 KNEEPAD

Kneepads are the protective gear worn on knees to protect the individual against impact injury during kicking the ball activity. This actually can cause strain and stress in the player's joint and if this condition is often happen, the knee of the player can have serious injuries and maybe there will be a lacking in performance for the player in football games (Shephard, 2003). So, in order to reduce this added stress to an athletes, the kneepad are worn so that it can give a protection to the important parts of the knee and it also will reduce the impact that exert on the knee.

Most of the football games that have been done, the safety equipment to be used by the athletes are not being emphasis by most of the sport organizer (Marshall *et. al*., 2002). Mora, 1996 state that by wearing the kneepad, it can avoid pain and injury in any activities. In football games, the players are most exposed to the higher risk of knee injury, rather than the others sport. It is because, football used a lot of knee movement so because of that footballer more exposed to get the knee injury. When the footballers are in the games, they will usually involve in the tackling incident, wrong landing of the knee during jumping and others (Collis and Llewellyn, 1924).

2.5 KNEEPAD MATERIAL PROPERTIES

2.5.1 Kenaf Material Properties

Kenaf also known as the Hibiscus cannabinus L is a plant that has been crop during the season of warm annually. This material also related to cotton and jute. At first, kenaf is used as a cordage crop, for the production of twine, rope and also sackcloth but in this new era, kenaf is mostly used in the paper production, building materials, absorbents and also for an animal feeds. Other than that, kenaf is now becoming the important source for composites and other industrial applications (Kamani, 1997).

Figure 2.14: Kenaf Fiber

In the terms of kenaf mechanical properties, generally it has higher values of flexural modulus and strength. Overall, mechanical test results for the sustainable composites manufactured in the industries, it shows the values that of the usage of the kenaf fiber a quite close to other polymer composites using nonrenewable synthetic fibers such as glass (Aziz *et al*., 2003).

Table 2.2: Kenaf Fiber material properties

Parameter	**Value**
Density	1.5 g/cm^3
Tensile Strength	930 MPa
Young Modulus	53 GPa

(Source: Rouison, 2004)

2.5.2 Coconut Pulp Fiber Material Properties

Coconut pulp or coir is a lingo-cellulosic natural fiber. It is a seed-hair fiber that can be getting from the husk, of the coconut fruit. The coconut pulp fiber industries are well developing in certain area of the world (Harisha, 2009). The coconut pulp fiber actually has its own specialties, in which it has characteristics of hard-wearing quality, durability and others; it is chosen to be used in the productions of certain materials like floor furnisher, yarn, rope and others. It is abundant, a renewable materials, cheap, versatile and can actually use to make a variety of products (Satyanarayana, 1982).

Figure: 2.15: Coconut Pulp Fiber

In terms of coconut pulp fiber mechanical properties, it possesses the lowest thermal conductivity and bulk density. The addition of coconut pulp fiber materials will reduce the thermal conductivity of the composite specimens and produces a lightweight product (Khedari, 2002).

Table 2.3: Coconut Pulp Fiber Material Properties

Parameter	**Value**
Flexural Strength	38 MPa
Density	1.15-1.46 g/cm^3
Young Modulus	4-6 GPa
Tensile Strength	131-220 MPa

(Source: Rouison, 2004)

2.5.3 Palm Oil Fiber Material Properties

Figure 2.16: Palm Oil Fiber

Palm oil fiber also known as the Empty Fruit Bunches (EFB) can actually be processed back and it can be used for the making of certain materials like the wood plastic, erosion control, landscaping and others. Palm oil fiber is abundant and can actually easy to get in Malaysia. It is because Malaysia is one of the biggest oil palm makers in the world. In order to make use of this palm oil fiber, it needs to be separated, refined and dried before it can be used. In terms of coconut pulp fiber mechanical properties, the employment of the palm oil fiber in mat from has produced polyurethane-empty fruit bunch (PU-EFB) composites with better properties where composite treated fibers have a superior tensile and flexural properties than those without treatment (Rozman, 2004).

Table 2.4: Palm Oil Fiber Material Properties

Parameter	**Value**
Density	0.7-1.55 g/cm^3
Young Modulus	3.2 GPa
Tensile Strength	248 MPa

(Source: Rouison, 2004)

2.5.4 Saw Dust Material Properties

Figure 2.17: Saw Dust

` Saw dust is a waste material from the timber industry and also from the wood making work. It is produced as timber or the wood is sawn into planks at saw mills. There are certain uses of the saw dust such as to make the fire starter, lighten the heft of mixed cement, to absorb used turpentine and mineral spirits with it, to fill holes and defects in wood, can be used as a mulch for landscaping, and others.

Table 2.5: Saw Dusk Material Properties

Parameter	Value
Density	0.19 g/cm^3
Young Modulus	0.386 GPa
Tensile Strength	21.9 MPa

(Source: Rouison, 2004)

2.6 JOURNAL

Table 2.6: Journal Summary

JOURNAL / ARTICLE	Simulation	Experimental	ACL	Kneepad	Jumping	Kicking
FIFA (1982) Statistics on the 150 affiliated national associations of FIFA. FIFA News 235 528		✓	✓	✓	✓	✓
Volpi P (2000) Soccer injury epidemiology. J Sports Traumatol 22: 123-131		✓	✓		✓	✓
Nilsson S, Roass A (1978) Soccer injuries in adolescents. Am J Sports Med 6:358–361		✓	✓		✓	✓
Eriksson E, Svensson L-I, San TK, Valentin A (1996) late results and sequaelae after soccer. In: Garrett WE Jr (Ed) The U.S. Soccer Federation sports medicine book of soccer. Williams & Wilkins, Philadelphia		✓	✓		✓	
Folksam Insurance Company (1994) Sports injuries 1986-1990. The 1994 Folksam report on 26,000 sports injuries studied on 1986-1990. Folksam, Stockholm		✓	✓		✓	✓
Ekstrand J, Gitlquist J, Liljedahl SO (1983) Prevention of soccer injuries. Supervision by doctor and physical therapist. Am J Sports Med 11: 116-120		✓	✓			✓
Piero Volpi, Gianluca Melegati, Davide Tornese, Marco Bandi Muscle strains in soccer: a five-year survey of an Italian major league team		✓	✓		✓	
MZ Bendjaballah, A Shirazi-Adl, DJ Zukor 1995. Biomechanics of the human knee joint in compression: reconstruction, mesh generation and finite element analysis.	✓		✓		✓	✓
Shunji Hirokawa!, Reiji Tsuruno 2000. Three-dimensional deformation and stress distribution in an analytical/computational model of the anterior cruciate ligament	✓		✓			✓

2.6.1 Simulation and Experimental

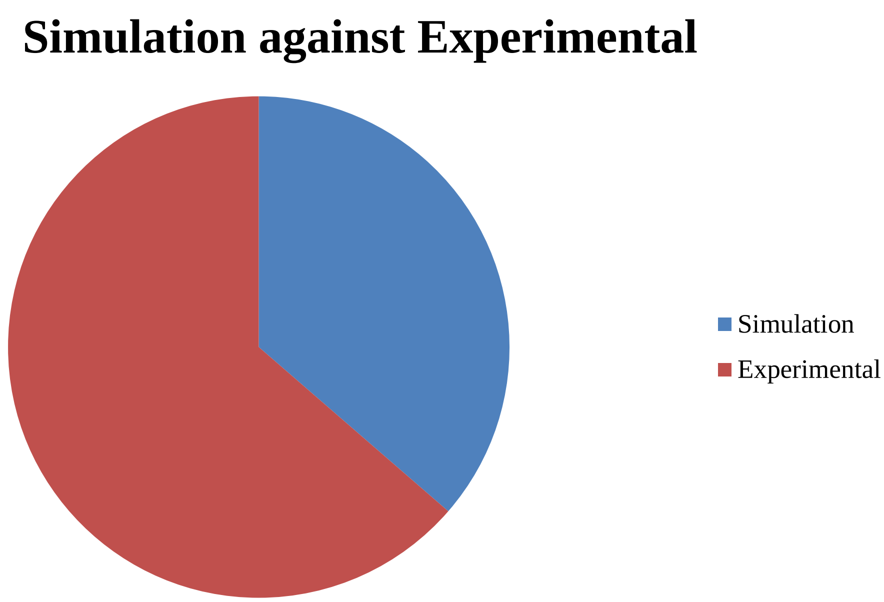


Figure 2.18: Simulation against Experimental

The figure above shows that the differences between the simulation and the experimental from the journal. The journal that has been studying, most of it more likely to do the experimental analysis rather than doing the simulation analysis because of the experimental result that we got from experiment is more accurate compare to the simulation result. It is because of the some value that not accurate when we're doing the simulation things example like when we kicking the ball, for the simulation we will applied the force regarding to the previous journal that write about the force applied but if were doing the experimental we do not need to consider the force applied because of the force applied from the ball is depending on the strength of the body while kicking the ball.

2.6.2 Kneepad

The journal that I found about the knee pad is not much. One of the journals that I found about the kneepad said that applying the kneepad is not necessary for a footballer. It is because of the absorb force that absorb from the knee pad is low. When we doing the kicking activities, the force applied is on the leg not the knee. That why the knee pad is not necessary to use in soccer games. But it still can use in order to avoid the unexpected incident while playing the soccer. Like example tackle from other players.

2.6.3 Jumping and Kicking

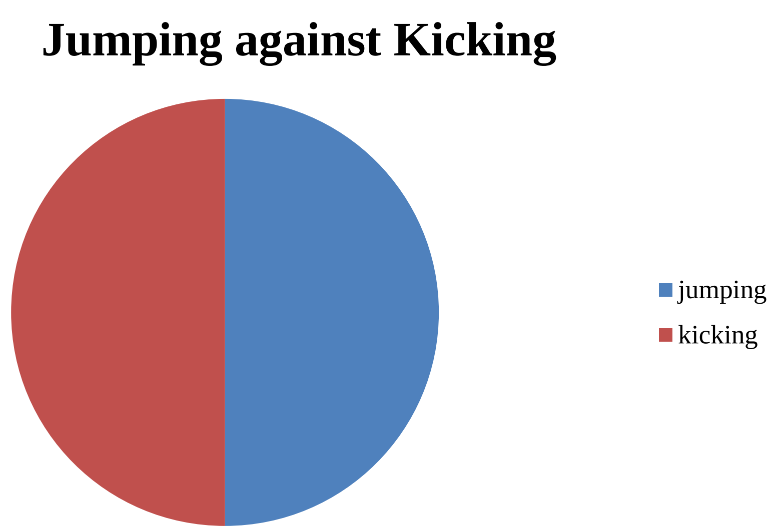


Figure 2.19: Jumping against kicking activities

Graph show that the kicking and jumping have the same percentages that ACL injury can occur. When we apply the kicking and jumping activities, the possibilities to have injury is high. It is because when we kicking or jumping there will be more posturer that will apply to it. All the body movement during kicking or jumping has the high probabilities happen twist or change in direction. This can cause the ligament especially the ACL to torn and injured.

CHAPTER 3

METHODOLOGY

This chapter will describe the detail of the methodology used in this study, by modeling and simulation the ACL. There are two sets of analysis which is the knee analysis using the knee pad and the other one is the knee analysis without the knee pad. The dimension of the ACL and the knee used in modeling was referred to the previous study. Besides, the parameters used to setup the simulation of the fluid and structure was based on the literature. The whole simulation was performed by using AUTODESK software. During the diastolic and systolic setup, the simulation was performed in a time period of 1 second and independent parameters like the flow and pressure variables was applied to the human knee.

3.1 DESIGN OF THE PROJECT

This final year project (FYP) being start with the title confirmation of the thesis where the title of the thesis is being given to the students. After student get the project title, first meeting with the supervisor has been made in order to get a briefing regarding about their project. The identification of the key point from the project title and the problem statement of the title given are very important to be known first, before the objective of the project has been stated. In the objective part of the study, student has to clearly understanding it so it’s easy for them to do the project smoothly without any mistakes. To get known about the objective of the project, student needs to discuss with their supervisor frequently. After that, student must identify the scope of the study of the research to be done. This part is really important because this scope is guiding the study field to be much clearer and closer about the title given.

3.2 FLOW CHART OF METHODOLOGY

In this methodology part, the flow chart will be represents a process by showing the steps of box that contains various kinds of shape like round, rectangle and also parallelogram. All of this shape is represent each step before the project done. Inside this shape has its own specific task and this task are linked together by every shape being connected with the arrows. Flow chart is use as the guideline for the researcher to do the things follow the flow of the project. It also help student to understand a process flow in a simple understanding and also will help to visualize the whole project from the start until the end.

On the other hand, the flow chart methodology that has been constructed is actually related to the scope of product as a guided principal to formulate this research successfully. It also is to ensure the achievement of the objectives being listed in this final year project research. Besides, the flow chart also can give a guide for the research experiment, in order for us to determine whether the task that we are doing is on the right track. The terminology of work and planning for this research was shown in the flow chart figure below.

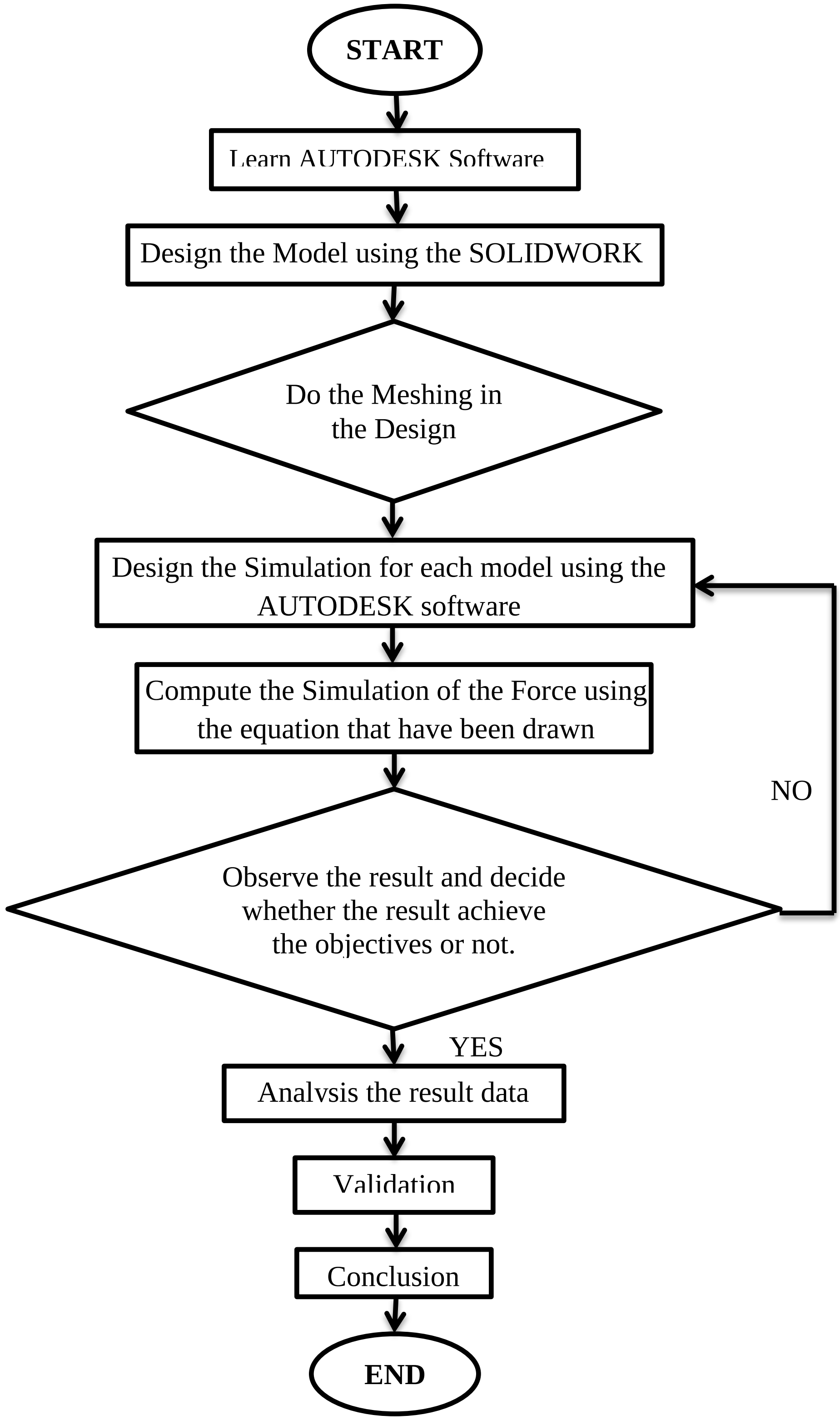


Figure 3.1: Flow Chart of the Project

From the flow chart above it can be said that this project is start with the introduction and ending with the conclusion. In this introduction, the clearance about the title is has been clear here. In this introduction also, the problem statement has been state and after the problem statement has been drawn, the objective will be come out from the problem statement. The scope of study will be drawn based on the objective. The scope of study will give the student a limitation from doing the research. When all of this was being understood, the project research can be continued to a further topic in the right track. After the introduction part was clearly understood, then the topic was further continued to the part of the literature review, in which in this section, there are an information that student need to find out about the details information that are related to the project, and need to state any information about the project flow, and any research from the past, to be used as the guideline in doing this project.

The next stage is the methodology stages. In this stage the simulation plan has been drawn based on the understanding from the literature review that has finished before. The calculation for each force distribution has been calculated in this chapter by using the proper equation. Next steps are by designing the knee model that includes the tibia bone, femur bone and also the ligament which is the ACL. This design is create in two different sets. The first set is the knee model that complete with the blood and skin and for another set is the complete knee with blood, skin and the kneepad. After finished the designing the knee, the simulation analysis has been done using the CAD software which is the AUTODESK software. The parameter for each part has been installed, the boundary condition has been defined and also the force distribution has been exerting on certain part on the knee.

After the simulation analysis process was finished, the data that get from the analysis has been analyzed using the Microsoft Excel software. Using this software the graph of stress against strain has been plotted based on each force distribution that has been applied and if the data that has been get from the simulation is not valid, the analysis has to been done again until the data that get from the simulation is valid. After the result has obtained, it is then being compared between bot of the sets. From comparing both of this set, we can identify which sets are better for the footballer to be used. Next step is conclusion and recommendation also being made for the future benefits in doing the project.

3.3 DESIGNING THE KNEE MODEL USING SOLIDWORK

SolidWork is the CAD software that used to design the three dimension model. For this research I have design one knee model which is including the femur bones and also the tibia bone. After that, I design the ligament which is the ACL. The design for ACL I also include the Anteromedial (AM) bundle and the Posterior (PL) bundle part. The AM bundle is the front part of the ligament and for the PL bundle; the part is at the back of the ligament. The dimension that used in this 3D model is same with the Asian human bones size. After the entire model finished, I assemble all the part into one part. By assemble all the part, the knee model for our analysis is completely finished. For this study I have been decide to use four different angle of flexion. The angle of flexion is 0^{o}, 45^{o}, 90^{o} and 155^{o}.

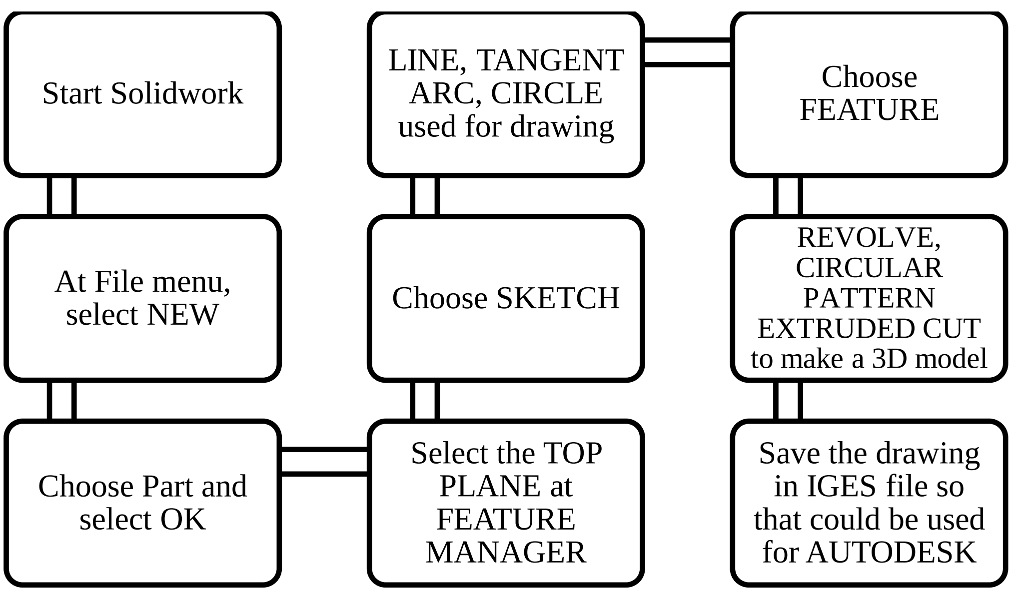
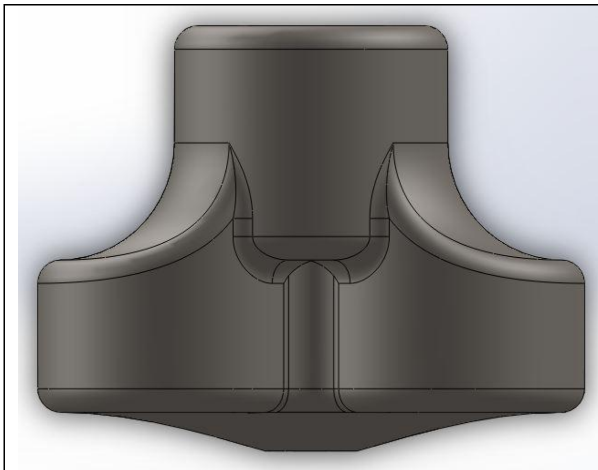
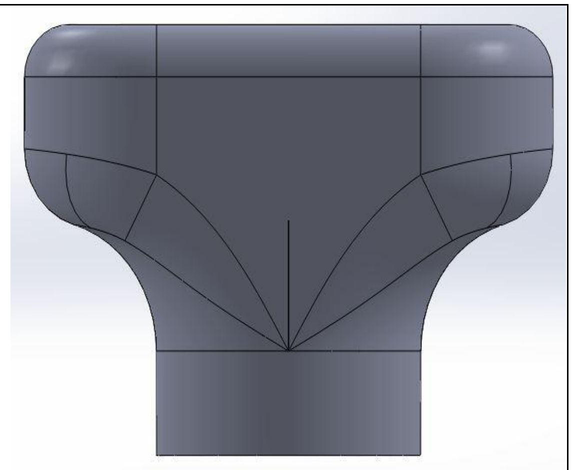
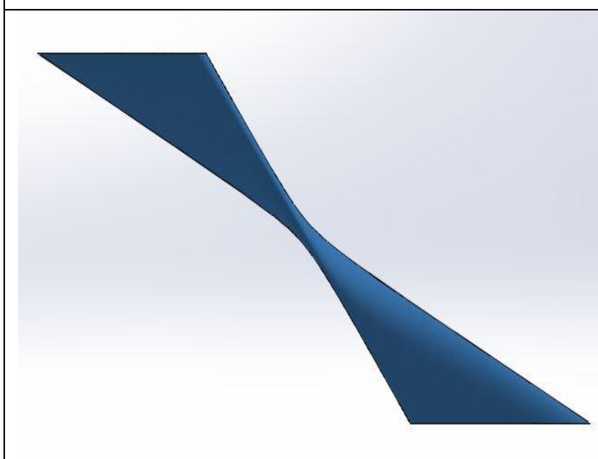
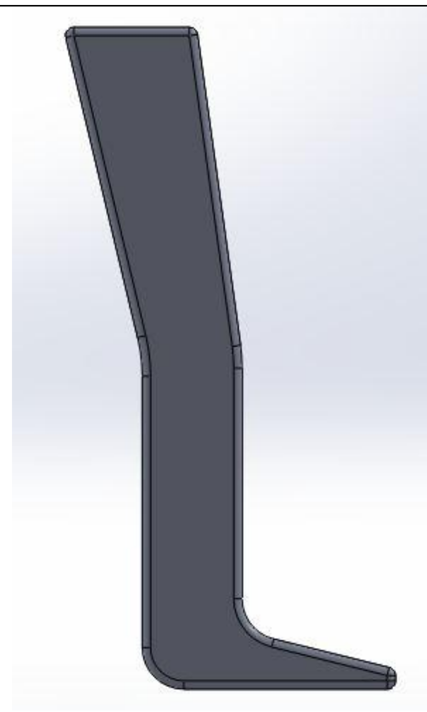
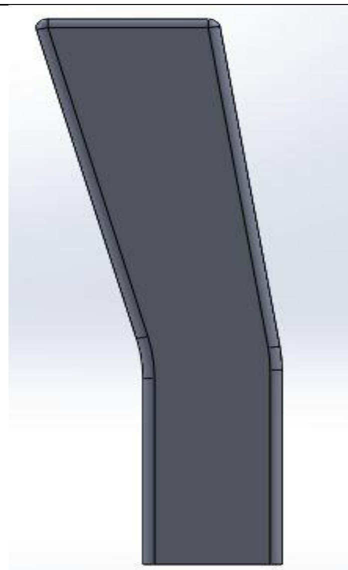
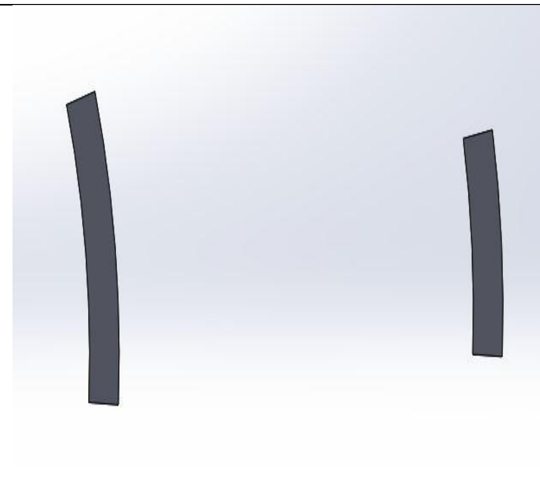


Figure 3.2: Solidwork Modeling Process Chart

Table 3.1: The Knee Part

	
Femur bone is placed at the upper part of the knee which is at the thighbone.	Tibia bone is placed at the lower part of the knee which is at the shinbone.
	
ACL is the ligament that placed at between of the femur bone and the tibia bone. This ligament is divided into two bundles. The first bundle is the AM bundle (front side) and the second bundle is the PL bundle (back side).	Skin is the outer part of the knee.

	
Blood is installed between the skin and the bone.	Kneepad is install at the skin which is at the outer of the knee. Kneepad is used as the absorber to absorb the force that exert on the knee.

3.4 SIMULATION

After finished with modeling the knee, this knee will analyze using the finite element method analysis (FEMPRO). AUTODESK is the software that will be used to run this analysis. AUTODESK is using to analyze the model and to determine the defect on the model when we applied the load. Reason choosing the AUTODESK as the third party to do the simulation is because of the function of the AUTODESK itself. It is because AUTODESK is mostly used to analyze the compression things. It's differing from other simulation software like ADINA. Function of ADINA is more to analyze the flow of the part.

My title for final year project asked me to analyze the behavior of the ligament with the knee pad and without the knee pad. So, from the title given I have come out with two sets of analyze. The first analysis is it to do the simulation using the knee pads. This analysis is including simulation in certain flexion angle while kicking the ball. The other analysis is to do the simulation without using the knee pads. This simulation analysis also will be run in certain angle of flexion after kicking the ball. The angle involve are the 0° flexion, 45° flexion, 90° flexion, 155° flexion. This entire angle is taking based on the body posture when soccer player want to kicking the ball.

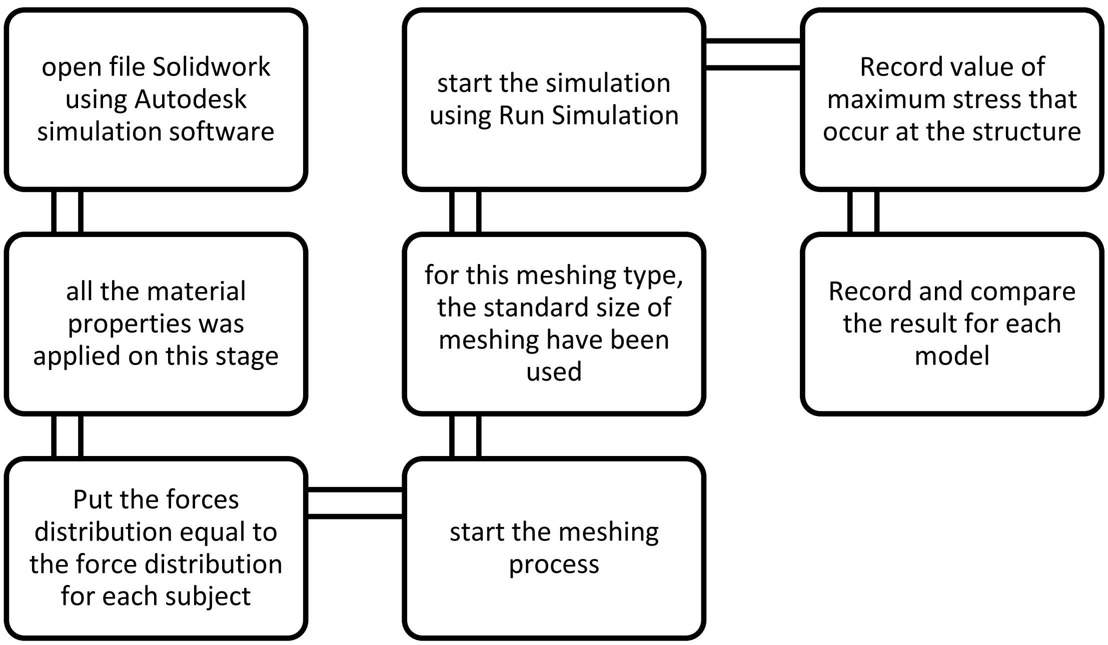


Figure 3.3: AUTODESK Analysis Process Chart

3.4.1 Numerical Simulation

In this project, the drawing of the knee was considered as a rigid body. The knee model will remain in its original shape and deformation is neglected during running and kicking in the simulation. The simulation mainly to investigate the effect of the displacement changes on the ligament and investigate in what condition the ligament disease occurs. For this study, there will be two types of kicking will be analyze. The first type is the side kick type and the second is the instep kick. The different for both of this type of kicking is the force that exert on the knee.

Figure 3.4: Side Kicking

Figure 3.5: Instep Kicking

For the side kick and instep kick there will be different angle of kicking. For side kick the angle is about 10 degree from the ball but 75 degree to the knee.

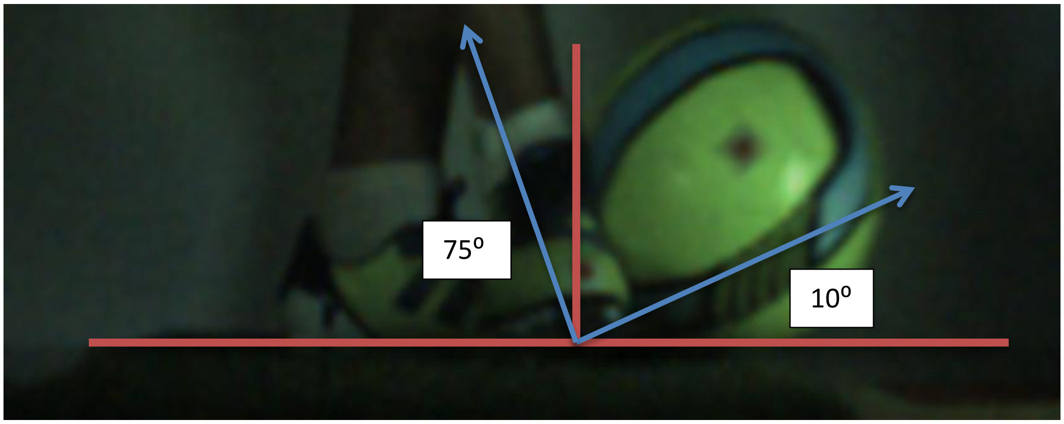


Figure 3.6: Side Kick Angle

The force distribution for this type of kicking is calculated using the formula of the resultant force. The data of the ball velocity is get from the experimental that been done before.

Table 3.2: Ball Speed for Each Subject

Type of Kicking	**Side Kicking**								
Subject	1			2			3		
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	15.54	14.19	15.12	16.95	18.35	16.89	19.09	19.53	21.11

From the table above the average ball speed for each subject have been calculate. The average for each subject have been calculate using this equation.

$$AM = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1 + a_2 + \cdots + a_n}{n}.$$

Table 3.3: Average Ball Speed for Each Subject

Type of Kicking	Side Kicking		
Subject	1	2	3
Average Ball Velocity (m/s)	14.95	17.40	19.91

From the velocity of the ball, we can calculate the force that exert from the ball.

For subject 1 ball velocity 14.95 m/s.

Knowing that,

$$Acceleration, a = \frac{velocity\ of\ the\ ball}{minimum\ time\ of\ impact}$$

$$a = \frac{14.95\ ms^{-1}}{0.01\ s}$$

$$\underline{\underline{a = 1495\ ms^{-2}}}$$

So,

$$Force, F = mass\ of\ the\ ball\ \times acceleration\ of\ the\ ball$$

$$F = 0.43\ (1495)$$

$$\underline{\underline{F = 642.85\ N \approx 643N}}$$

So from the force, we calculate the force distribution on the knee.

Knowing from the figure 3.7, the angle distribution on the ball is 10 degree.

So,

Resultan force on x-axis

$$F_x = F\cos 10^{0}$$

$$F_x = 643N\cos 10^{0}$$

$$\underline{\underline{F_x = 633.23N}}$$

For this situation we consider the third newton's law. Third newton's law state that when one body exert a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.

From the figure 3.7, the angle between the ball and the knee is 75 degree.

So,

$$F_{knee} = 633.23N \cos 75^{0}$$

$$\underline{\underline{F_{knee} = 163.89N \approx 164N}}$$

For the subject 2 and 3, the calculation for force distribution same with the subject 1.

Table 3.4: Ball Force and Force Distribution

Type of Kicking	**Side Kicking**		
Subject	1	2	3
Force (N)	643	748	856
Force Distributed (N)	164	191	218

For the instep kicking type the angle is different from the side kicking type. For instep we using angle knee

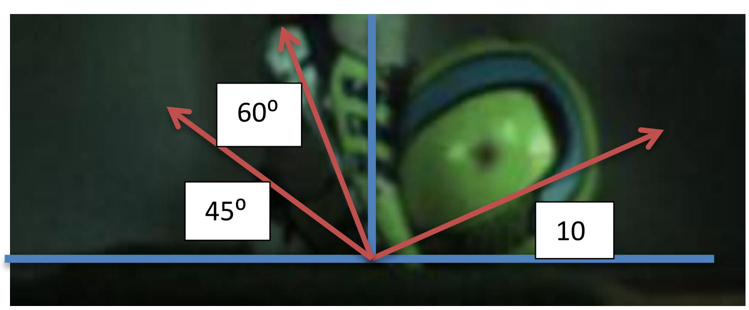


Figure 3.7: Instep Kick Angle

The force distribution for this type of kicking is calculated using the formula of the resultant force. The data of the ball velocity is get from the experimental that been done before. After calculate the average of the ball speed, the ball force for each subject will be calculated. From the force of the ball, the distribution force will be calculated using the angle that showed on figure 3.8. This data will be used as the force that will be exerting on the knee went analyze the simulation of the knee.

The average of the ball speed will be calculate using this equation

$$AM = \frac{1}{n}\sum_{i=1}^{n} a_i = \frac{a_1 + a_2 + \cdots + a_n}{n}.$$

Table 3.5: Ball Speed for Each Subject

Type of Kicking	**Instep Kicking**								
Subject	1			2			3		
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	16.27	18.54	16.50	20.97	20.06	16.69	24.89	24.23	25.27

Table 3.6: Average Ball Speed for Each Subject

Type of Kicking	**Instep Kicking**		
Subject	1	2	3
Average Ball Velocity (m/s)	17.10	19.24	24.80

When the average ball speed been calculate, the force of the ball and the force distribution of the ball will be calculate using the same equation as before but different in angle taken. This angle was taken from the experiment that has been done before.

For subject 1 ball velocity 17.10 m/s.

Knowing that,

$$Acceleration, a = \frac{velocity\ of\ the\ ball}{minimum\ time\ of\ impact}$$

$$a = \frac{17.1\ ms^{-1}}{0.01\ s}$$

$$\underline{\underline{a = 1710\ ms^{-2}}}$$

So,

$$Force, F = mass\ of\ the\ ball\ \times acceleration\ of\ the\ ball$$

$$F = 0.43\ (1710)$$

$$\underline{\underline{F = 735.3\ N}}$$

So from the force, we calculate the force distribution on the knee.
Knowing from the figure 3.7, the angle distribution on the ball is 10 degree.
So,
Resultan force on x-axis

$$F_x = F\cos 10^{0}$$

$$F_x = 735.3N\cos 10^{0}$$

$$\underline{\underline{F_x = 724.13N}}$$

For this situation we consider the third newton's law. Third newton's law state that when one body exert a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.

Because of the instep kicking type, we need to considered the angle of the sole. So for this case, the angleof the sole is 45 degree. So from the resultant force that been calculate before, the resultant force for the sole will be calculate.

$$F_{x1} = F_x \cos 45^{0}$$

$$F_{x1} = 724.13N \cos 45^{0}$$

$$\underline{\underline{F_{x1} = 512.04N}}$$

When the resultant of the sole have been calculate, the force distribution on the knee will be calculate.

So,

$$F_{knee} = 512.04 \cos 60^{0}$$

$$\underline{\underline{F_{knee} = 256.02N \approx 256N}}$$

For the subject 2 and 3, the calculation for force distribution same with the subject 1.

Table 3.7: Ball Force and Force Distribution

Type of Kicking	**Instep Kicking**		
Subject	1	2	3
Force (N)	735.30	827.30	1066.40
Force Distributed (N)	256	288	371

3.4.2 Material Selection (Anterior Crucial Ligament)

3.4.2.1 Fibroblasts

Cells in ligament called as the fibroblasts. National Human Genome Research Institute said that a fibroblast is a type of cell that synthesizes the extracellular matrix and collagen, the structural framework (stroma) for animal tissues, and plays a critical role in wound healing. Fibroblasts are the most common cells of connective tissue in animals.

3.4.2.2 Component in the ligament

Table 3.8: Component in Ligament

Component	Ligament
Cellular materials	
Fibroblasts	20 %
Extracellular	
Water	60-80 %
Solids	20-40 %
Collagen	70-80 %
Type I	90 %
Type III	10 %
Ground substance	20-30 %
Elastin	Up to 2x collagen

3.4.3 Parameter Setup

Table 3.9: Material Properties for Knee

Ligament (ACL)	Young Modulus	11000 MPa
	Poisson Ratio	0.4
Femur Bone	Young Modulus	20000 MPa
	Poisson Ratio	0.2
Tibia Bone	Young Modulus	14000 MPa
	Poisson Ratio	0.2
Skin	Young Modulus	200 kPa
	Poisson Ratio	0.49
Blood	Young Modulus	$3.5 \text{ X } 10^{-3}$ Pa
	Poisson Ratio	0.49

Table 3.10: Material Properties for each Kneepad

Kenaf	Density	1.5 g/cm^3
	Tensile Strength	930 MPa
	Young Modulus	53 GPa
Coconut Fiber	Density	1.46 g/cm^3
	Tensile Strength	6 MPa
	Young Modulus	220 MPa
Palm Oil Fiber	Density	1.55 g/cm^3
	Tensile Strength	3.2 GPa
	Young Modulus	248 MPa
Saw Dusk	Density	0.19 g/cm^3
	Tensile Strength	0.386 GPa
	Young Modulus	21.9 MPa

3.5 MESHING

Meshing process used to be the one of most important step to determine the accuracy of result obtained in simulation. In our study, Arbitrary Lagrange Euler (ALE) mesh was used during the setup in simulation. Hart et al (2003) stated that to solve the multidimensional such as two-dimensional numerical simulation problems which involved fluid dynamics and nonlinear solid mechanics, it always required coping with strong distortions of the continuum under consideration while allowing for a clear delineation of fluid–fluid, solid–solid, or fluid–structure interfaces (J. Donea, Antonio Huerta, J.-Ph. Ponthot and A. Rodr´ıguez-Ferran 2004).

In the ALE explanation, the nodes in the computational mesh could be moved either with the continuum in normal Lagrangian fashion or be held fixed in Eulerian method. In Lagrangian method, it stated that each individual node in the computational mesh follows the associated material particle during movements, which usually apply in the structural mechanism. The disadvantage for Lagrangian method is it unable to apply during large distortions of the computational domain without depends on redo meshing operations. Furthermore, Eulerian method is widely applied in fluid dynamics where the mesh is fixed and continuum moves with respect to the grid. It is different with Lagrangian method where it could handle with large distortions in the continuum motion.

CHARTER 4

RESULT AND DISCUSSION

In this chapter, the simulation result obtained from the analysis on the knee joints are presented and discussed. Both of the knee sets are simulate using same force distribution which is 474N, 768N, 909N and 977N. The finite element method software is used to simulate the knee joint. The result in form of graph stress values against strain was plotted. The comparison between both sets also has been decided. As for the validation, the comparison between calculation value and simulation value has been made.

4.1 SIMULATION RESULT

Finite Element Analysis (FEA) provides a reliable numerical technique for analyzing engineering designs. The process starts with the creation of a geometric model. Then, the program subdivides the model into small pieces of simple of simple shapes (elements) connected at common points (nodes). Finite element analysis programs look at the model as a network of discrete interconnected elements.

The Finite Element Method (FEM) predicts the behavior of the model by manipulating the information obtained from all the elements making up the model. Meshing is a very crucial step in design analysis. The automatic mesher generates a mesh based on a global element size, tolerance, and local mesh control specifications. Mesh control lets specify different sizes of elements for components, faces, edges, and vertices. Before redraw the knee joint, it needs to be measure from a real thing of knee joint and also get the actual size of the knee part.

4.2 DESIGN STUDIES.

A model is usually subjected to different service environments and operational conditions during its life. It is therefore important to consider all possible scenarios of loads and boundary conditions and try different material properties in the analysis of a model.

i. Designs are defined by some factors:
ii. Model dimensions
iii. Study type and related options to define the analysis intent
iv. Material properties
v. Loads and tangential load

4.3 STUDY TYPES

Static Studies has been used in this project. A static study is about calculate displacements, reaction forces, strains, and also stresses. Material fails at locations where the stresses exceed a certain level.

4.4 MATERIAL MODELS

A material model describes the stress-strain relation for a material. A linear elastic material model describes the elastic behavior of a material in the linear range. The material dialog box offers two types of material models:

i. Linear Elastic Isotropic
ii. Linear Elastic Orthotropic

4.5 SIMULATION RESULT FOR KNEE WITHOUT THE KNEEPAD

4.5.1 Simulation result for 0degree flexion.

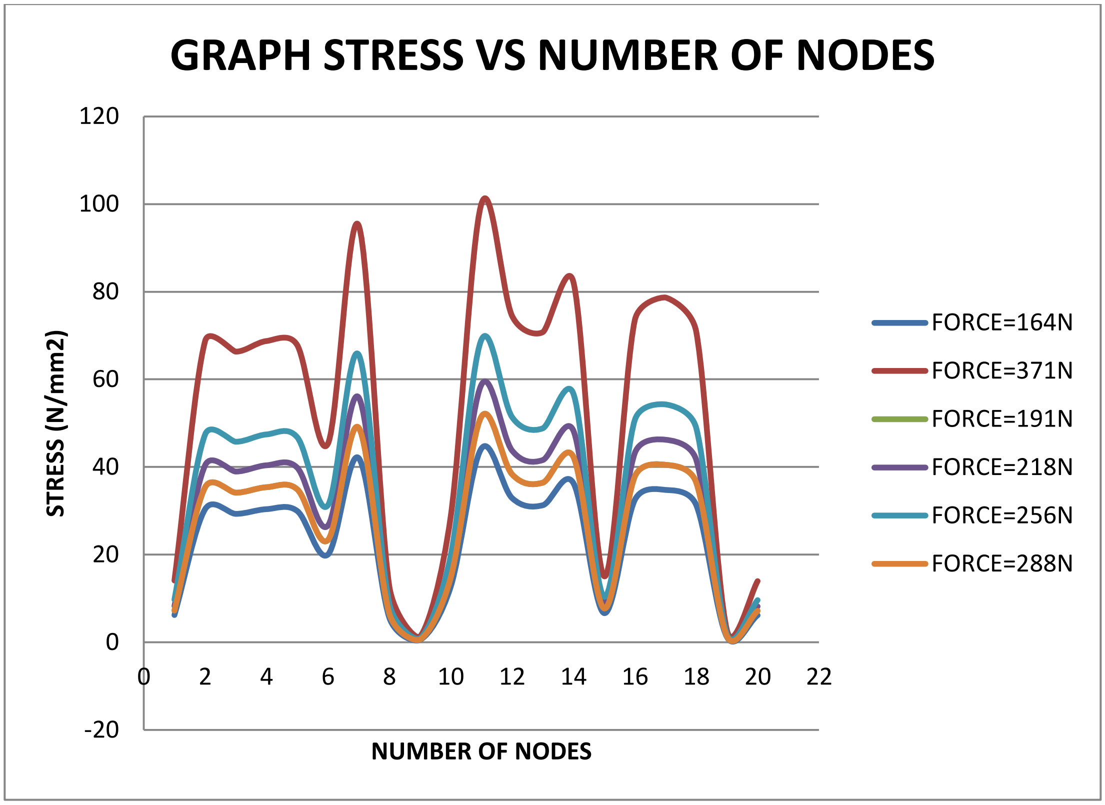


Figure 4.1: Result for 0degree flexion

The graph shows the distribution of the force for six different force distributions at the joint. It can be seen that the maximum stress value is occur at force distribution equal to 371N which is 100.0317872 N/mm2. The results are taken with the forces from 164N until 371N base on the velocity that gets from experimental. These forces supposed to divide into two categories which are the instep kick and also side kick. The different between these two types of kicking is only the force distribution. So for the analysis, there will be no different between these two kinds of kicking.

It shows that, the ligament was most affected when high force distribution applies to it. From the graph the highest value of stress occur when 371N which is the highest force apply to it and for the lowest stress value occur at the lowest force distribution applied to knee which is 164N. The different of stress occurs is highly due to the different force applied on the knee joint. It clearly state that, the highest stress value for 371N was 100.0317872 N/mm2 and the highest stress value of 164N is 44.21905184 N/mm2.

Theoretically, more force applied on knee joint, more stress value will occur. The high stress value occur, the ligament will have high possibility to occur injury it is because the ligament only can accept the certain value of force exert on it.

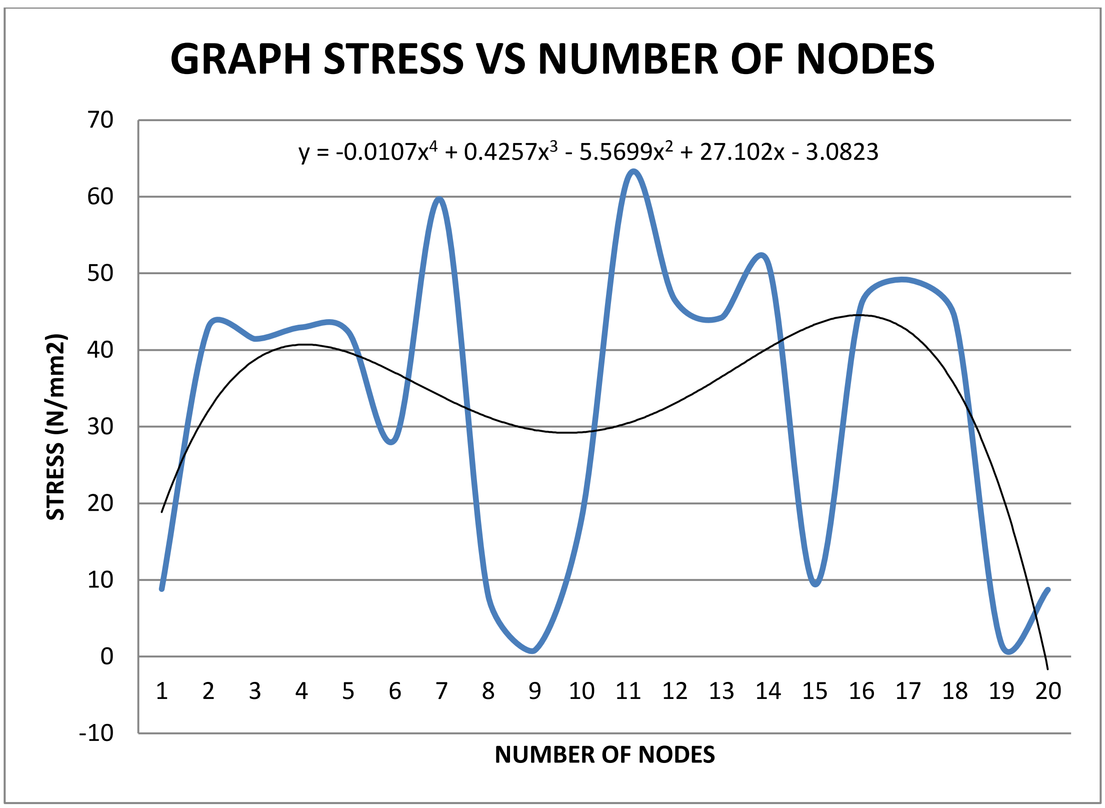


Figure 4.2: Average Graph for 0degree Flexion

The graph shows the average graph for each force distribution on knee. The data is get from the average equation for each node. In this graph, the regression line was created. From the regression line, the equation will be created. The equation of regression line will be used as the validation for the simulation result. The number of certain node will be applied at the equation and the stress value will be calculated.

The graph of stress value of simulation data and calculation data will be calculated and the error between both graphs will be calculated. Form result obviously shows that the stress values that get from the calculation will be not same with the simulation data but the value is approximate to the simulation. So because of the calculation data is almost the same with the simulation data, so the data form the simulation was valid and can be used.

4.5.2 Simulation result for 45degree flexion.

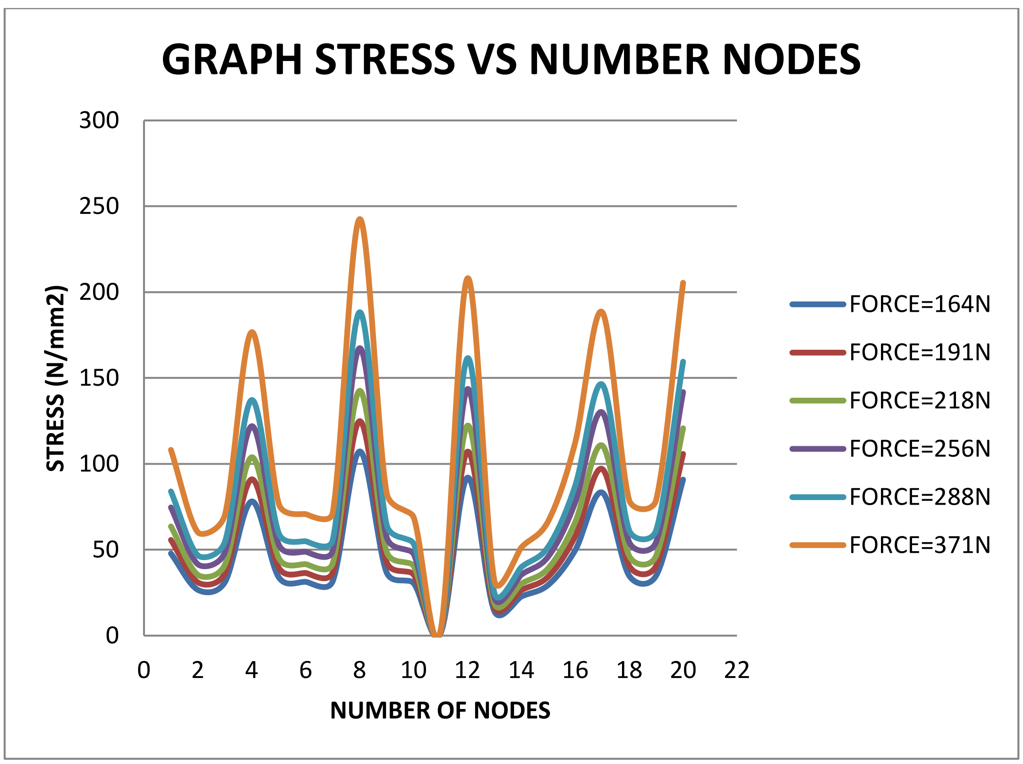


Figure 4.3: Result for 45degree Flexion

According to the graph, the stress values of the knee joint increase linearly according to the increasing force distribution. The stress graph actually shows how the stress of the ligament effect when the force distribution was increase. The graph shows the maximum and minimum value of stress for each force distribution. Overall stress value, the maximum stress value was 242.4861552 N/mm2 which is at force distribution equal to 371N and the minimum stress value was 2.655303375 N/mm2 which is for force distribution equal to 164N.

With this result, it can be told that between these two types of kicking there will be no different for ligament because the different between these two types only at the force distribution. It means that, whether each of these types of kicking is used, injury still can occur to the ligament. If the force exert on knee is high; whether side kick or instep kick, it still will occur injury.

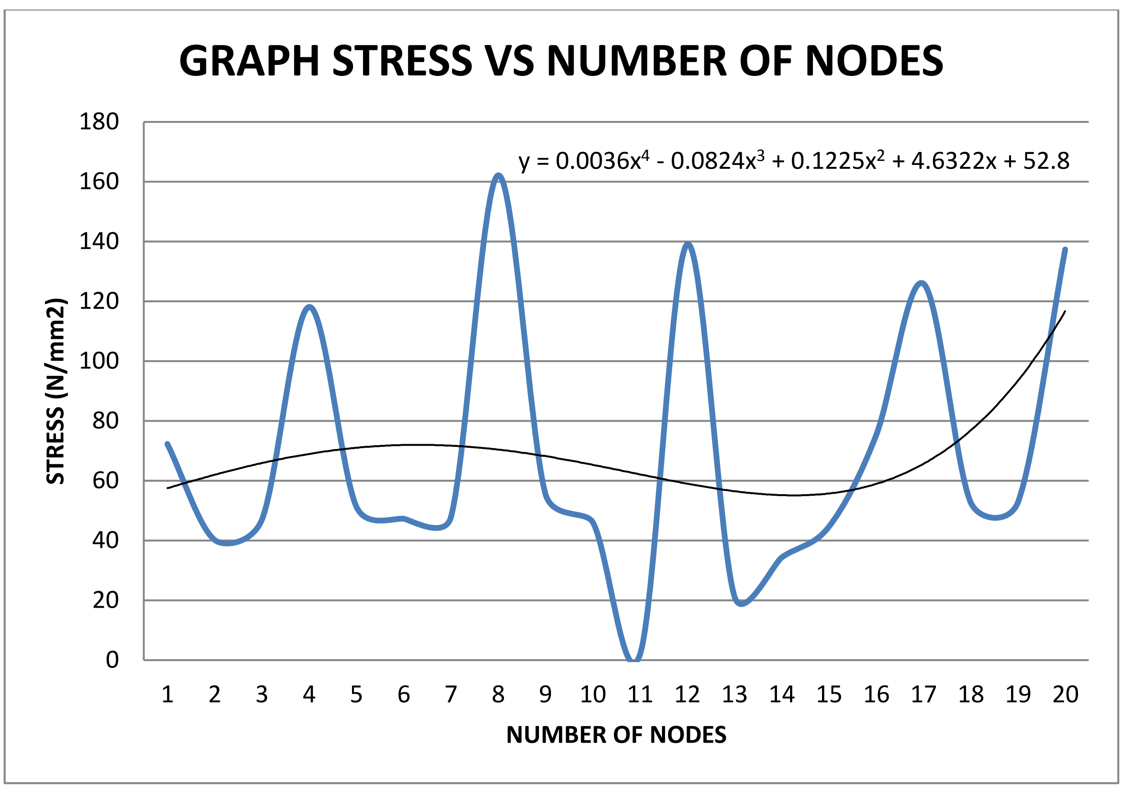


Figure 4.4: Average Graph for 45degree Flexion

The above graph shows the average graph for 45degree knee flexion. The average data was get from the calculation of the average of each stress value for each force distribution. From the data that have been calculate, this graph was created. This graph will be used as the comparison between each angle of flexion use during the kicking activities. The equation for validate the stress values vas create by created the regression line from this average data.

From the equation that has been create, the x value is the nodes number and for the y value is the stress values. To validate the stress value, the certain nodes number will be substitute into this equation and the stress value will be produced from this equation. The different between these two stress values is not far. The gaps between these two values is not that big and because of that, the stress values that get from the simulation can be consider as valid and can be used.

4.5.3 Simulation result for 90degree flexion.

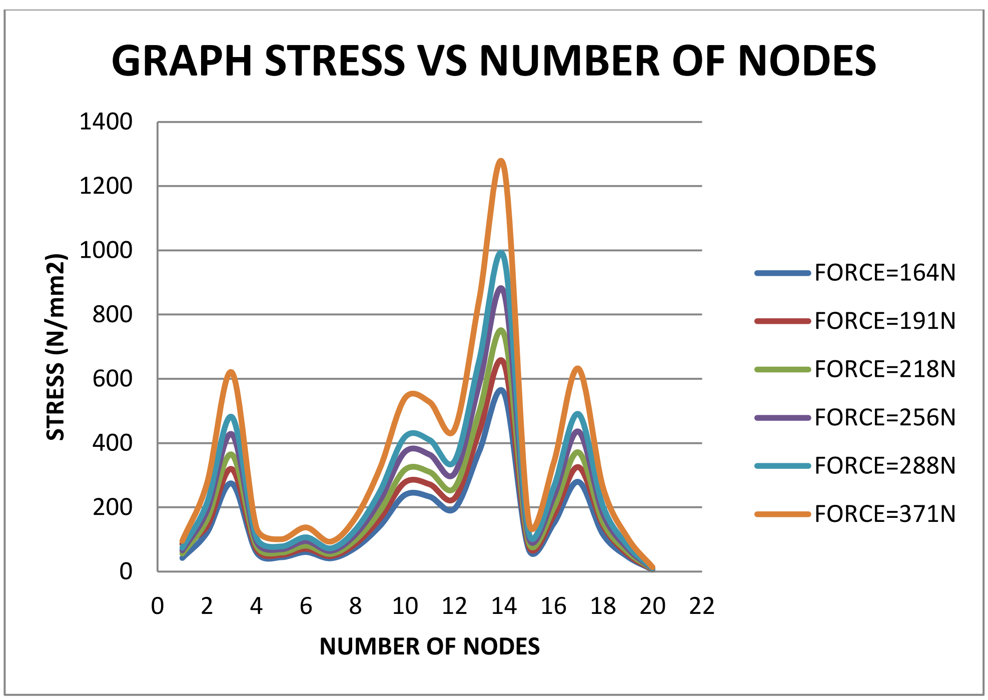


Figure 4.5: Result for 90degree Flexion

The graph shows the stress value result that gets from the simulation of 90degree of knee flexion which being used versus with the nodes number. The simulation is done by six different force exert on the knee. This force get base on two different types of kicking which is the side kicking and instep kicking. It can be seen that the highest stress was shows at force distribution equal to 371N and the lowest stress value was at force distribution equal to 164N.

This is same with other angle flexion which shows that the force is directly proportional to the stress values. The maximum stress value is 1257.945879 N/mm2 which occur at 371N and the minimum stress value is 13.63066992 N/mm2 which is occur at 164N. With these results, it can be concluded that when a bigger force is applied, the stress values might pass through the necking and fracture. Therefore, this could be stopped by understanding the maximum stress value that ligament can extend until it reach its limit before the ligament is injured.

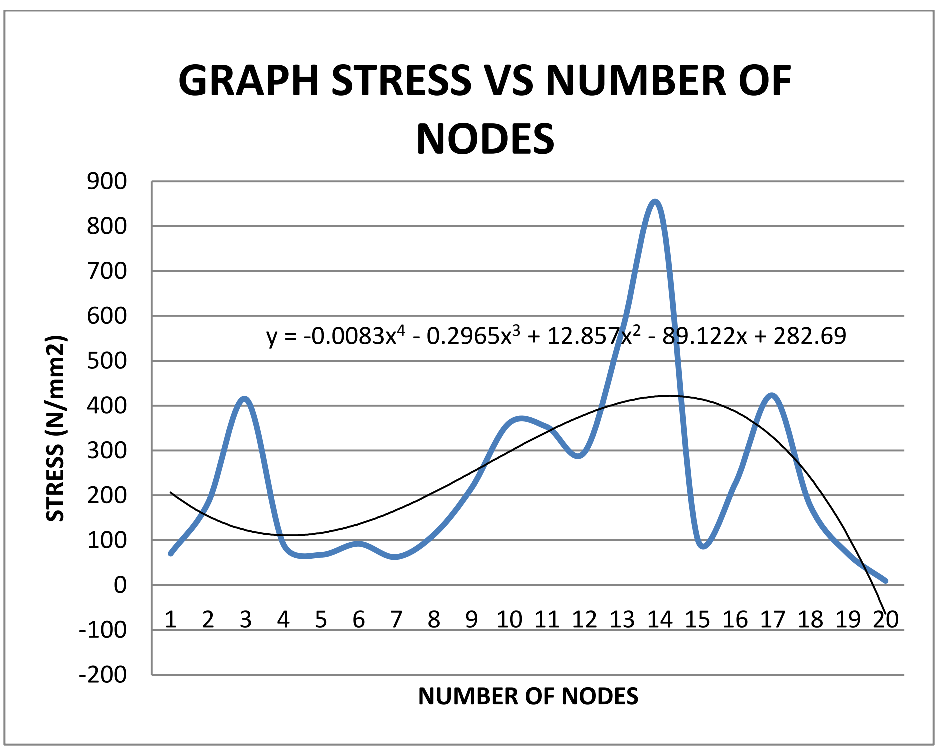


Figure 4.6: Average Graph for 90degree Flexion

The above graph was created so the regression line can be created to calculate the new stress value based on the node number. From the stress values get from the calculation, this value will be compared to the simulation data. When comparing these two data, we can conclude that the different between these two data is slightly differing and because of that, the data that get from the simulation is considered as valid.

From the equation, the x values are the node number and for the y values are the stress values. To calculate the stress value which is y, the number of nodes will be substitute into the equation. So when the stress value was get, that values will be compared to the simulation data to validate whether the simulation data can be used or not. This data also will identified whether the equation that been created can be used or not to identify the next number of nodes.

4.5.4 Simulation result for 155degree flexion.

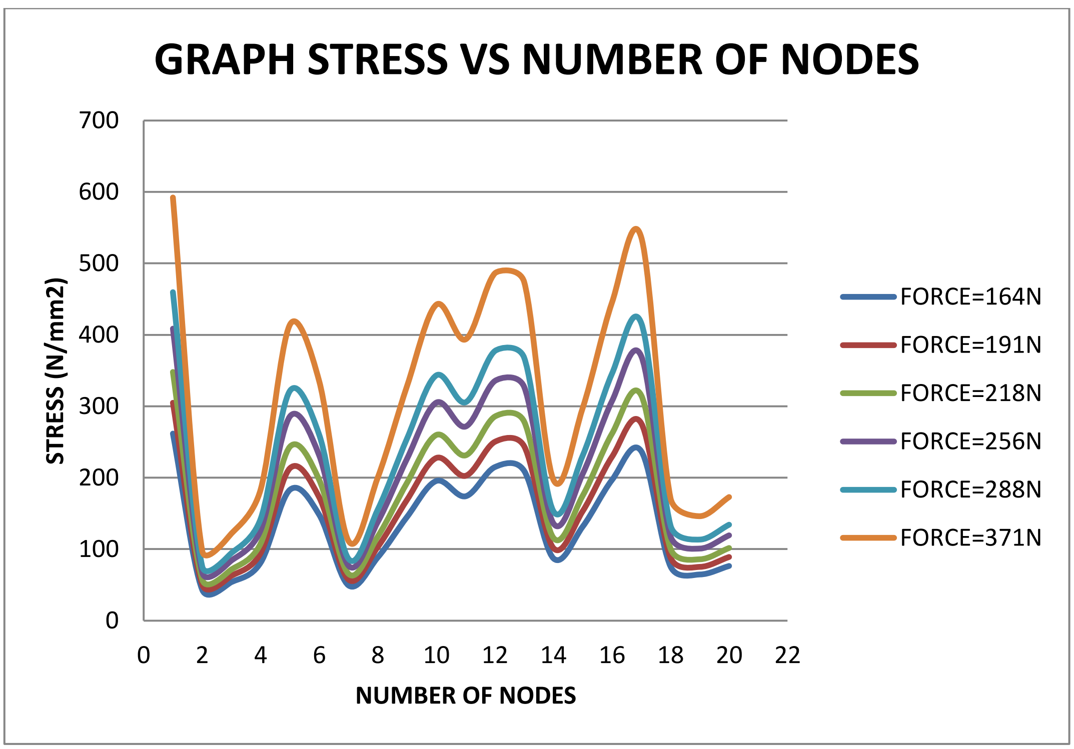


Figure 4.7: Result for 155degree Flexion

The graph above shows the graph stress against the number of nodes. From this graph it was cleared that the maximum stress occur when 371N of force distribution exert on the knee joint and for the minimum stress occur when force distribution occur at 164N. From this graph, it shows that the highest the value of force distribution, the highest stress value occur at ligament.

The ligament has its own limit that it can sustain. If it's reach its limitation, the ligament have high possibility to occur injury that can abandon the footballer players. To avoid this from happening, the player should avoid some unexpected force that to high so the knee will not get any injuries and also it can avoid the ligament from fracture of torn. Most of the footballer player that get this injury which is the ligament injury, they maybe will not able to continue their passion in football field. People need to alert and know that the internal compartment in our body is so sensitive and it's hard to recover when one of it injured.

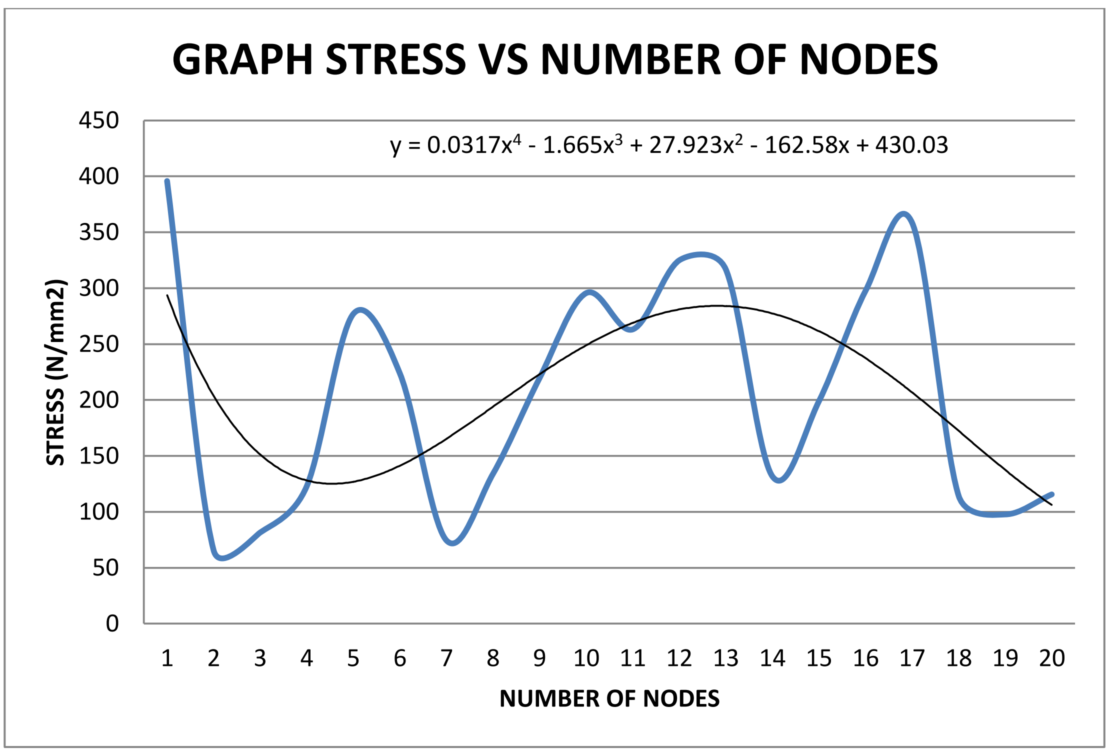


Figure 4.8: Average Graph for 155degree Flexion

The graph shows the average of the stress value for 155degree flexion for each force distribution. Reason for plotted this graph was to create the regression line that will be used to form an equation that will be used later for validation part. The equation that produced from this regression line will be used to calculate the new stress value based on the nodes number for each node. This stress values after that will be compare each other with the simulation stress values.

The differences between these two stress values can define whether the simulation data was valid or not to be used. It also can identified whether the equation that form from the regression line can be used or not to identify the new stress value for new nodes number. The equation is creating so it's easy to the reader to identify the stress value for certain nodes number around the knee joint including around the ligament itself.

4.6 SIMULATION RESULT FOR KNEE WITH THE KNEEPAD

4.6.1 Simulation result for Von Stress analysis (material: Kenaf)

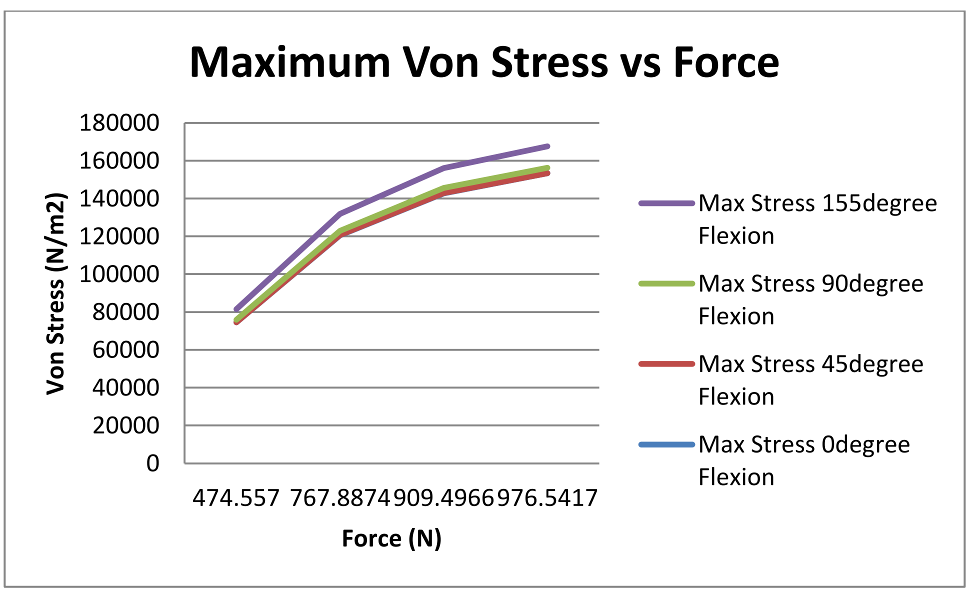


Figure 4.9: Graph Maximum Von Stress Values vs. Force Distribution

The graph shows the distribution of the stress for four different types of knee flexion. It can see that from that graph stress versus force retrieved from the finite element software is reaction every each knee angle from stress to force. The results are taken with force distribution from 474N until 977N. This is because; the maximum force that the footballer can attend force. It shows that our knee cannot accept the force more than that range of force. More than that force can cause them to get serious injuries. It also can cause the performance of the footballer will down.

It shows that, with the same amount of force, the least stress affect to the knee angle of flexion is from knee angle of 45degree which is about 11309.35 N/m2 from force distribution equal to 977N and it became decreased to 1393.899 N/m2 at force distribution of 474N. It is clearly shown that, the force is directly proportional with the von stress. From the graph, more force exert on the knee joint, the maximum stress will be increased. So, from the graph we can conclude that the maximum stress value is affected by the force distribution that exert on it.

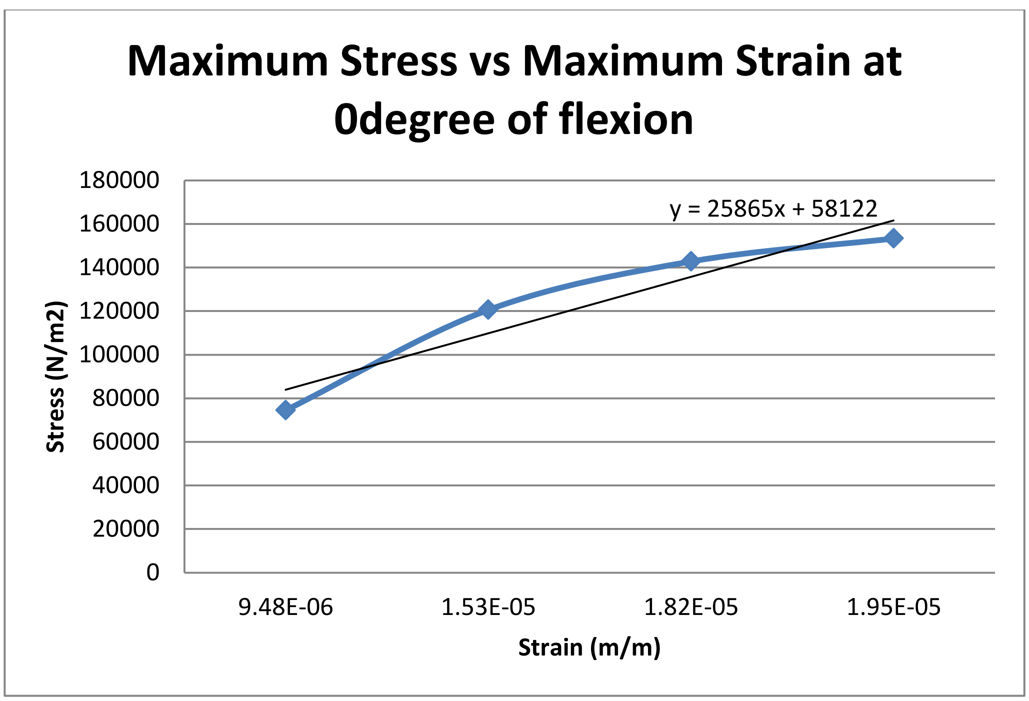


Figure 4.10: Maximum Stress vs. Strain for angle of flexion equal to 0degree

The graph above shows the maximum stress versus maximum strain for angle of flexion equal to 0degree. It shows that, with the different value that got from the analysis finite element method, the graph of force distribution above shows that the highest value of stress is at strain value equal to 1.95E-5 and the lowest goes at the strain point 9.48E-6.

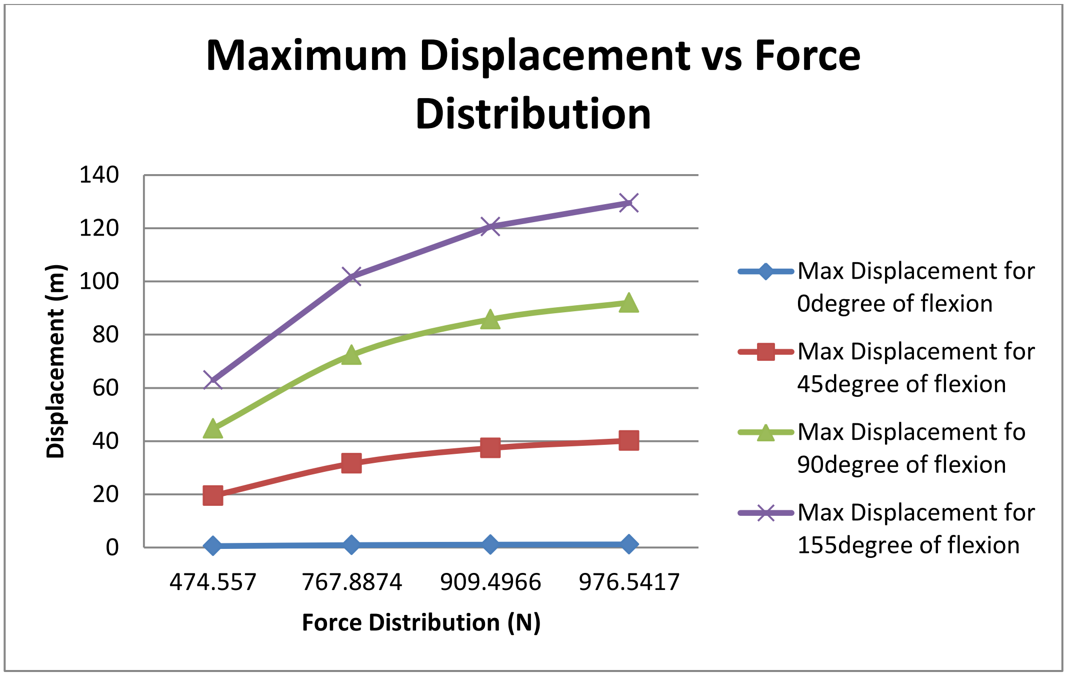


Figure 4.11: Maximum Displacement vs. Force Distribution Graph for each angle of knee flexion.

Graph above shows the comparison result for the maximum displacement versus the force distribution for each angle of flexion. From the graph above, it clearly shows that the maximum displacement occur at the knee flexion equal to 155^{o} and for the lowest displacement occur at the 0^{o} flexion. At 0^{o} flexion, the ligament is not stretch it at its steady state which means the ligament is the full extension. For the 155^{o} the ligament is stretch more rather than when ligament at the full extension. At this point, the ligament used to be a full flexion. Full flexion means the knee maximum flexion that can reach.

4.6.2 Simulation result for Von Stress analysis (material: Coconut)

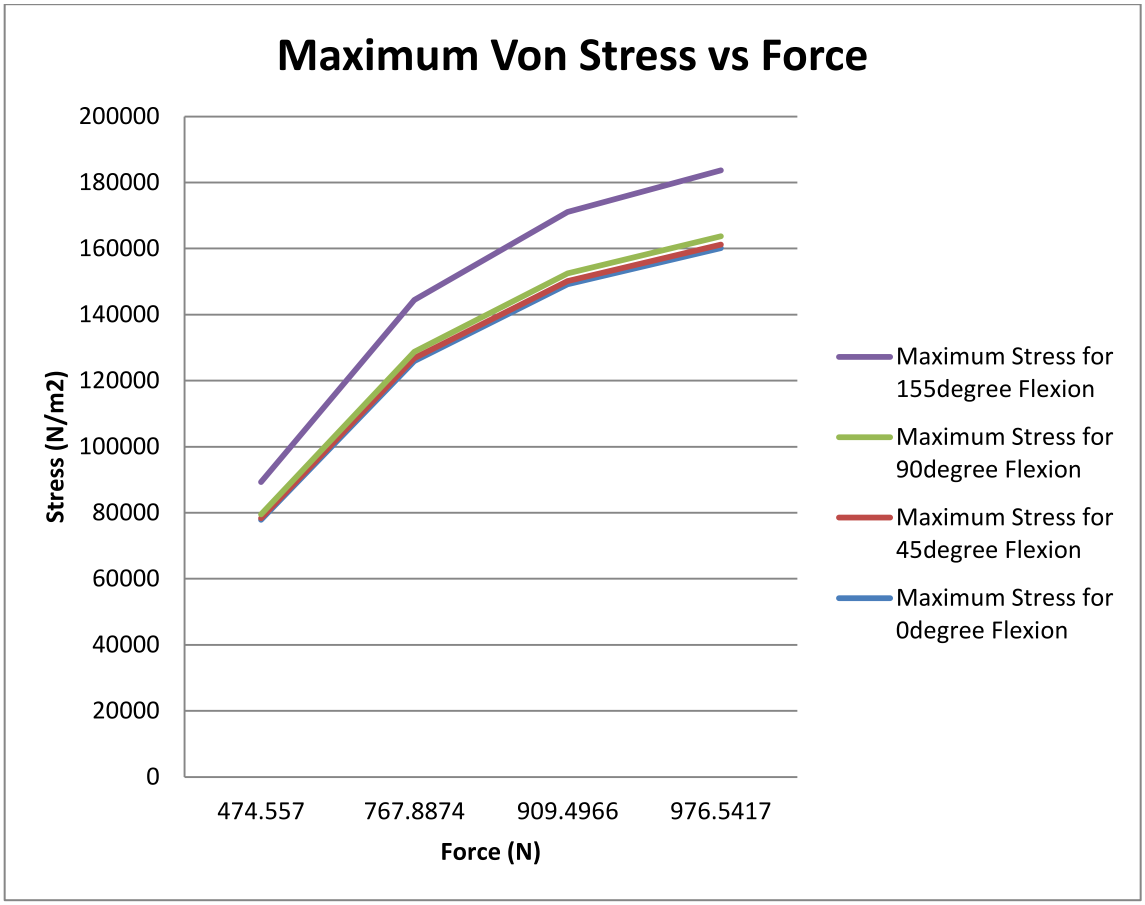


Figure 4.12: Graph Maximum Von Stress Values vs. Force Distribution

According to the graph, the stress values of the knee joint increase linearly according to the increasing force distribution. The stress graph actually shows how the stress of the ligament effect when the force distribution was increase. The graph shows the maximum and minimum value of stress for each force distribution. Overall stress value, the maximum stress value was occur at the 155^{o} of knee flexion and for the lowest is it happen at the 45^{o} of flexion.

The ligament has its own limit that it can sustain. If it's reach its limitation, the ligament have high possibility to occur injury that can abandon the footballer players. To avoid this from happening, the player should avoid some unexpected force that to high so the knee will not get any injuries and also it can avoid the ligament from fracture or torn. Most of the footballer player that get this injury which is the ligament injury, they maybe will not able to continue their passion in football field. People need to alert and know that the internal compartment in our body is so sensitive and it's hard to recover when one of it injured.

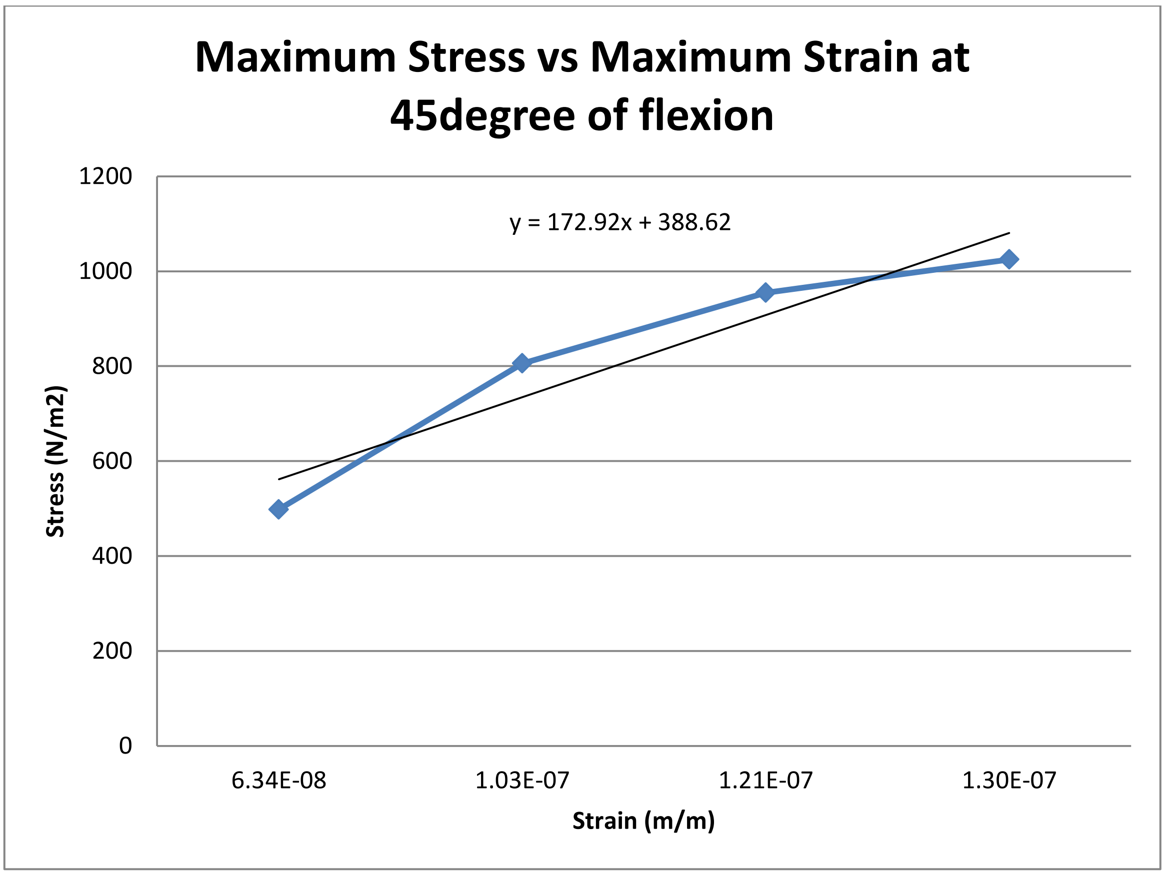


Figure 4.13: Maximum Stress vs. Strain for angle of flexion equal to 45degree

The graph above shows the maximum stress versus maximum strain for angle of flexion equal to 45degree. It clearly shows that, with the different value that got from the analysis finite element method, the graph of force distribution above shows that the highest value of stress 1024.973 N/m2 and for the lowest is 498.1219 N/m2. From the graph, the regression line has been made to simplify the graph pattern. From the regression line, the equation of the linear line has been made. This equation is used to identify for the next strain value or stress value.

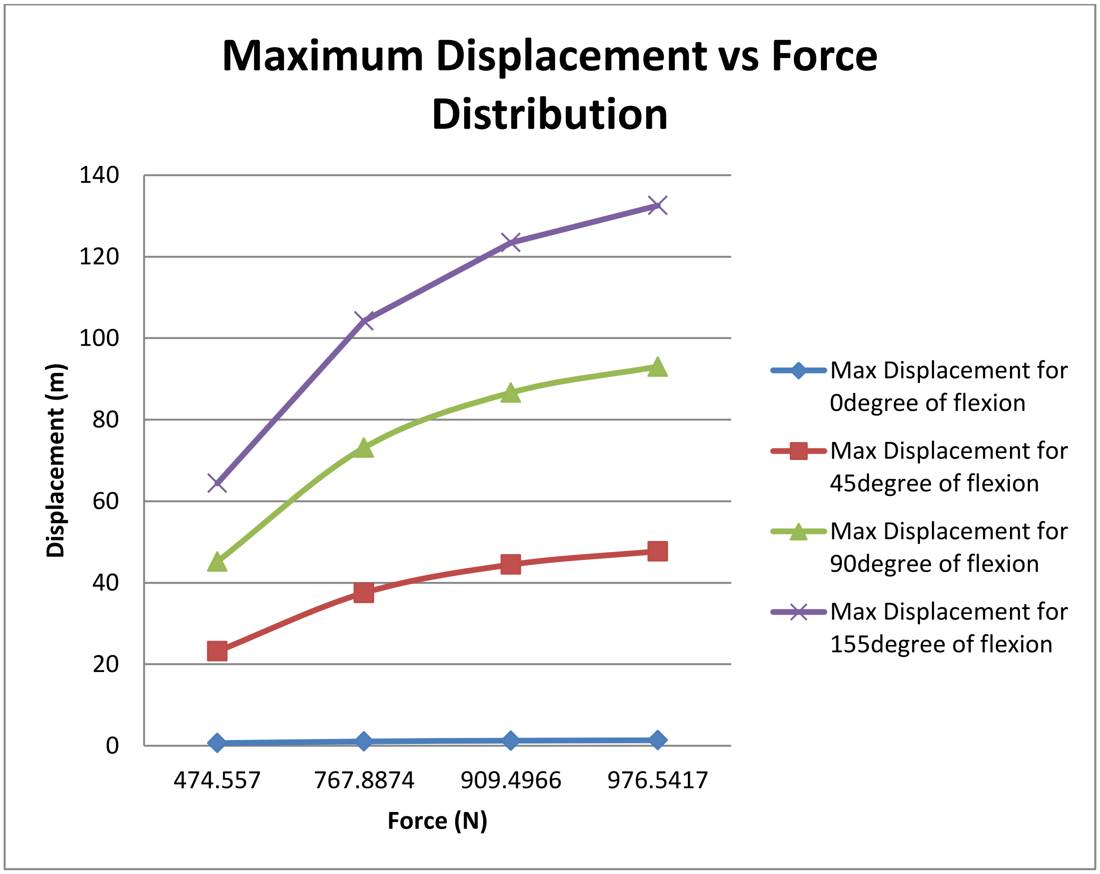


Figure 4.14: Maximum Displacement vs. Force Distribution Graph for each angle of knee flexion.

Graph above show the result for the maximum displacement versus the force distribution for each angle of flexion. Same as the graph for kenaf kneepad, the maximum occur at 155^{o}and the minimum occur at 0^{o} of flexion. As shown at the graph, the displacement of the ligament is affected by the force distributions that occur at it. Higher the force distribution that means higher displacement has occurred. It can simplify that the displacement of the ligament is directly proportional to the force distribution that has been applied.

4.6.3 Simulation result for Von Stress analysis (material: Palm Oil)

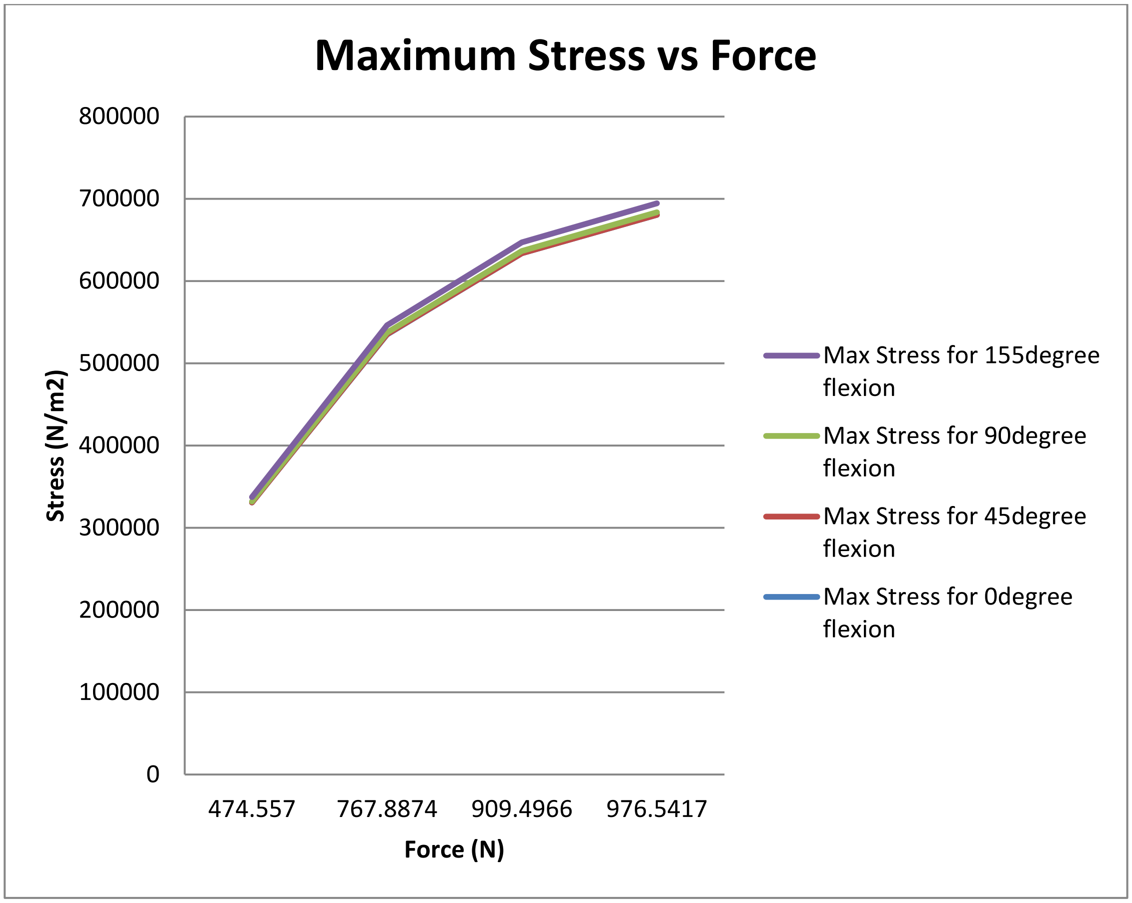


Figure 4.15: Graph Maximum Von Stress Values vs. Force Distribution

Graph above shows the comparison between stress and the force distribution for each knee flexion. This graph was plotted so that the different stress that recorded from the simulation can be seen through this graph. From the graph, it clearly shows that the different between each of the angle of flexion is not that differ. The maximum stress occurs at the angle knee flexion equal to 155^{o} and for the lowest it occurs at 0^{o}.

Theoretically, more force applied on knee joint, more stress value will occur. The high stress value occur, the ligament will have high possibility to occur injury it is because the ligament only can accept the certain value of force exert on it.

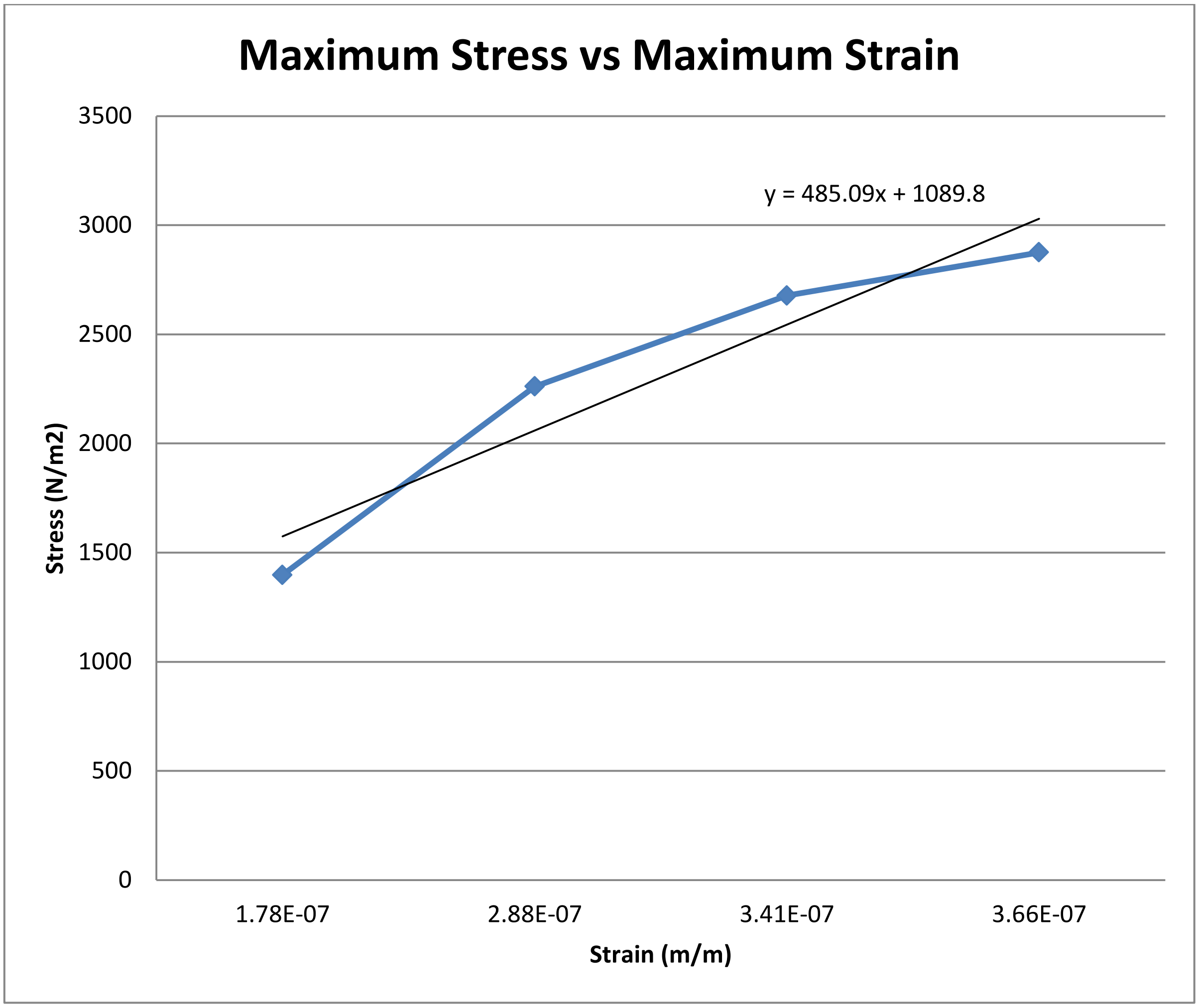


Figure 4.16: Maximum Stress vs. Strain for angle of flexion equal to 90degree

Graph above shows the result of the stress versus strain for angle flexion equal to 90degree. From the graph, it can be conclude that the stress is affected by the value of strain. Higher stress values means, higher strain values. From the graph, there is a equation which is gets from the regression line that has been made as a simplified from the actual graph. This equation is used to identify the next value for stress or strain. From the equation, it can be conclude that the stress value is affected about 485.09 value of strain.

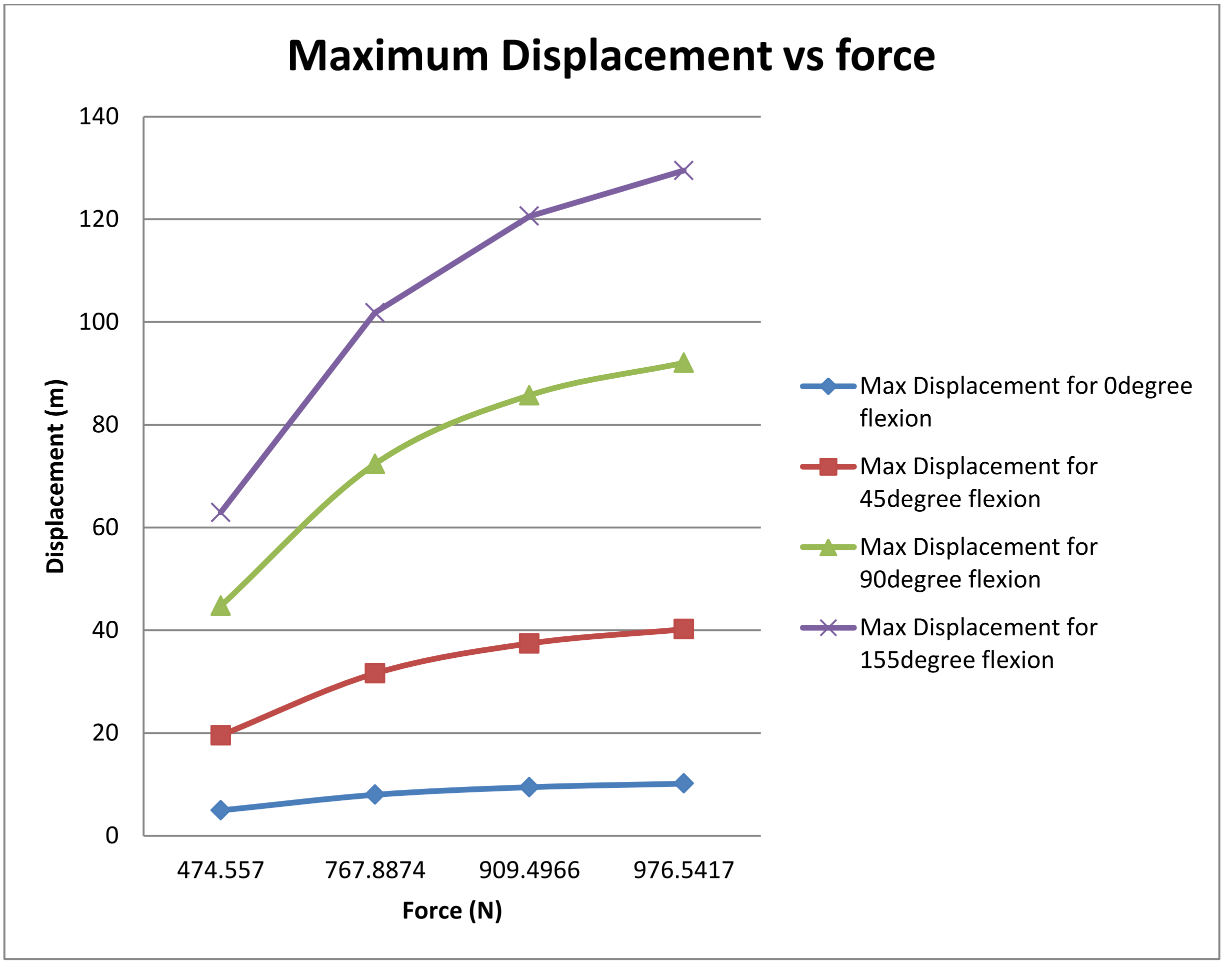


Figure 4.17: Maximum Displacement vs. Force Distribution Graph for each angle of knee flexion.

From the graph above it clearly shows that the maximum displacement occurs at the angle of 155^{o} of flexion and for the lowest displacement occur at 0^{o} of flexion. It shows from the graph that the displacement is affected by the force distribution that exert on it. It can be concluded that the displacement is directly proportional to the force distribution for each angle of flexion.

4.6.4 Simulation result for Von Stress analysis (material: Saw Dusk)

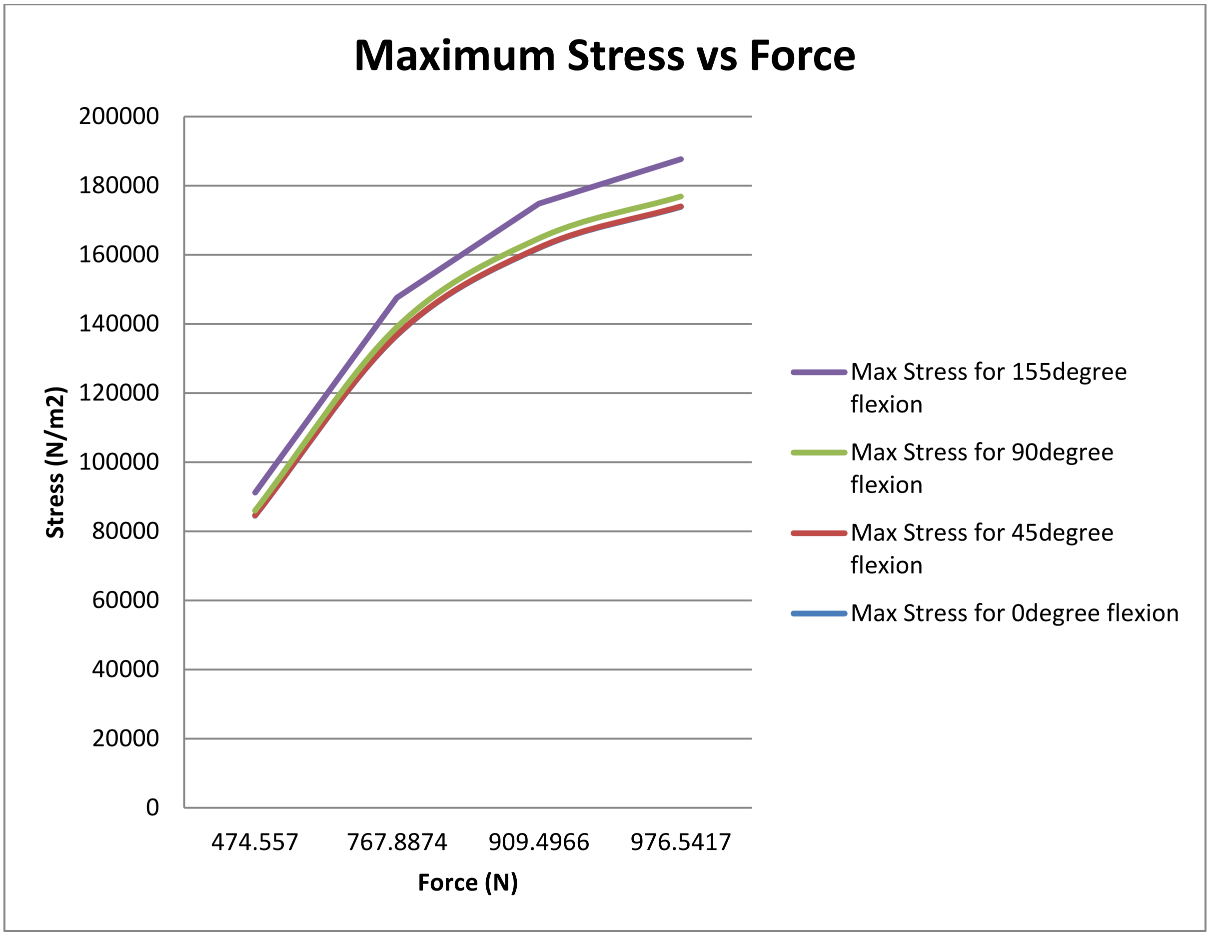


Figure 4.18: Graph Maximum Von Stress Values vs. Force Distribution

Graph show the graph of stress versus force for each angle of flexion. From the graph, it clearly shows that the maximum stress occur at 155^{o} and for the lowest stress occur at 0^{o} of flexion. The force distribution that has been used is only used to see the pattern of the graph and to identify whether the stress effected by the force or not. So, from the data that has been got from the simulation, we can conclude that the force distribution effect the stress value. Higher force distribution exert on knee means higher stress value will be recorded.

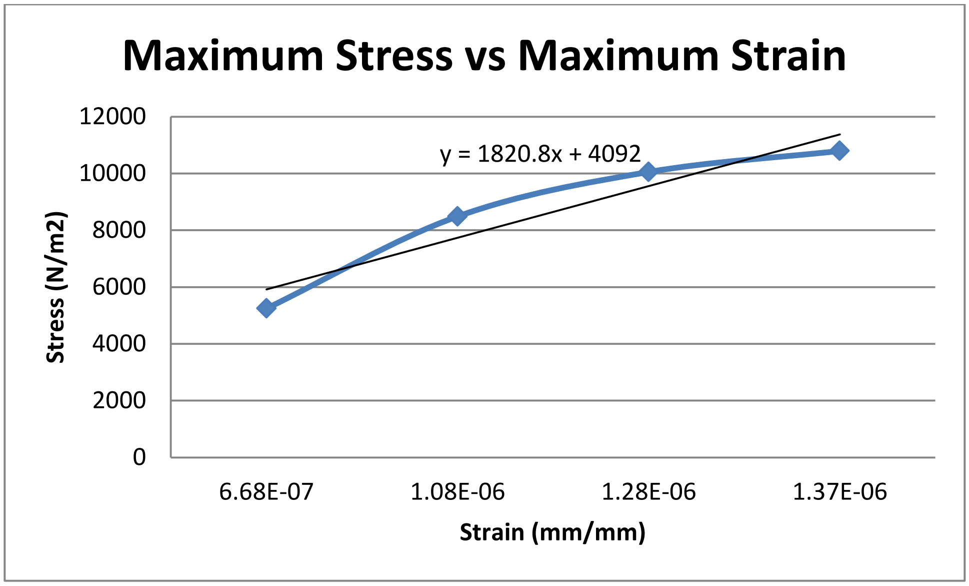


Figure 4.19: Maximum Stress vs. Strain for angle of flexion equal to 155degree

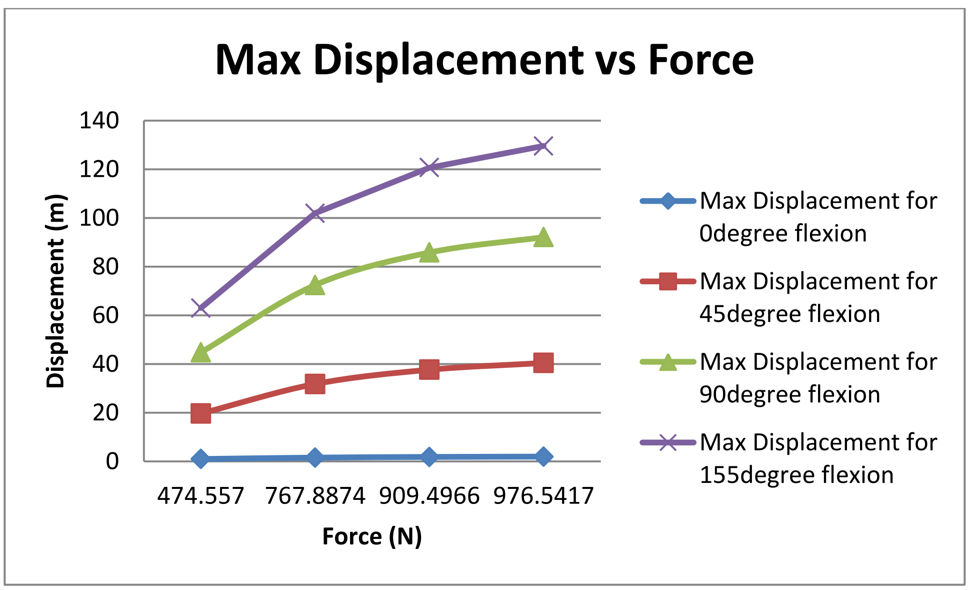


Figure 4.20: Maximum Displacement vs. Force Distribution Graph for each angle of knee flexion.

Graph above shows the graph of the stress versus strain and another graph show the result for the maximum displacement versus the force distribution. For graph stress versus strain, we can conclude that the higher stress values mean higher strain values. The stress values act directly proportional to the strain value. For that graph the regression line has been plotted and the regression equation has been made. Reason for this equation making is too easy for us to identify the next stress value or the next strain value.

For the second graph, it clearly shows that the displacement at 155^{o} angle of flexion recorded the highest values and for the 0^{o} angle of flexion recorded the lowest values. It is because at the 0^{o} of knee flexion, the ligament is at it steady state which is the full extension state or in other words it called as the rest state. For the 155^{o} of knee flexion, the knee is at the maximum states that it can undergo flexion. at this point the position called as the full flexion which means this is the last angle that human knee can undergo.

4.7 NUMERICAL CALCULATION

This numerical calculation is calculated to do the validation part. The reason by doing this numerical calculation is so the error between the calculation and the simulation data can be identified. So by doing this method, we can identify whether the data that we get from the simulation is valid or not.

4.7.1 Galerkin analysis

By assuming the ACL as a beam,

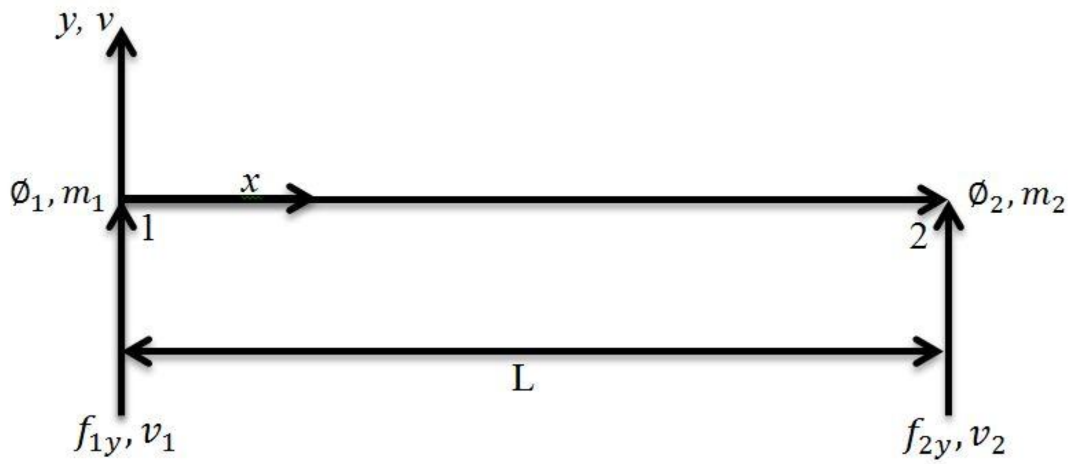


Figure 4.21: Beam element with Positive Nodal Displacements, Rotations, Forces and Moments.

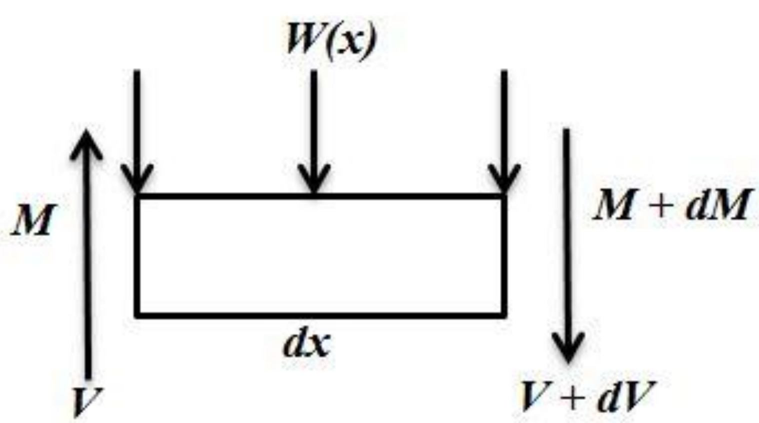


Figure 4.22: Differential Beam Element

From the force and moment equilibrium of a differential element of the beam, we have

$$\Sigma f_y = 0; V - (V + dV) - w(x)dx = 0 \qquad 4.1.1a$$

Or, simplifying equation 4.1, we obtain

$$-wdx - dV = 0 \; or \; w = -\frac{dV}{dx} \qquad 4.1.1b$$

$$\Sigma M_2 = 0; \; -Vdx + dM + w(x)dx\left(\frac{dx}{2}\right) = 0 \;\; or \;\; V = \frac{dM}{dx} \qquad 4.1.1c$$

The final form of equation 4.1.1c, relating the shear force due to the bending moment, is obtained by dividing the left equation by *dx* and then taking the limit of the equation as *dx* approaches 0. The *w(x)* term then disappears.

Also, the curvature ҁ of the beam is related to the moment by

$$ҁ = \frac{1}{\rho} = \frac{M}{EI} \qquad 4.1.1d$$

Where ρ is the radius of the deflected curve, *v* is the transverse displacement function in the *y* direction, *E* is the modulus of elasticity and *I* is the principle moment of inertia about the *z* axis.

The curvature for small slopes $\emptyset = dv/dx$ is given by

$$ҁ = \frac{d^2v}{dx^2} \qquad 4.1.1e$$

Using equation 4.1.1e in 4.1.1d, we obtain

$$\frac{d^2v}{dx^2} = \frac{M}{EI} \qquad 4.1.1f$$

Solving the equation 4.1.1f for *M* and substituting this result into 4.1.1c and 4.1.1b

$$\frac{d^2}{dx^2}\left(EI\frac{d^2v}{dx^2}\right) = -w(x) \qquad 4.1.1g$$

For constant *EI* and only nodal forces and moment, equation 4.1.1g becomes

$$EI\frac{d^4v}{dx^4} = 0 \qquad 4.1.1h$$

Assume the transverse displacement variation through the element the element length to be

$$v(x) = a_1x^3 + a_2x^2 + a_3x + a_4 \qquad 4.1.2$$

We express *v* function of the nodal degrees of freedom $v_1, v_2, \emptyset_1, \emptyset_2$ as follows:

$$\begin{aligned} v(0) &= v_1 = a_4 \\ \frac{dv(0)}{dx} &= \emptyset_1 = a_3 \\ v(L) &= v_2 = a_1L^3 + a_2L^2 + a_3L + a_4 \\ \frac{dv(L)}{dx} &= \emptyset_2 = 3a_1L^2 + 2a_2L + a_3 \end{aligned} \qquad 4.1.3$$

Where $\emptyset = dv/dx$ for the assumed small rotation $\emptyset$. Solving equation 4.1.3 for a_1 through a_4 in term of the nodal degrees of freedom and substituting into equation 4.1.2, we have

$$v = \left[\frac{2}{L^3}(v_1 - v_2) + \frac{1}{L}(\emptyset_1 + \emptyset_2)\right]X^3 + \left[-\frac{3}{L^2}(v_1 - v_2) - \frac{1}{L}(2\emptyset_1 + \emptyset_2)\right]x^2 + \emptyset_1x + v_1 \qquad 4.1.4$$

In matrix form, we express equation 4.1.4 as

$$v = [N]\{d\} \qquad 4.1.5$$

Where

$$\{d\} = \begin{Bmatrix} v_1 \\ \emptyset_1 \\ v_2 \\ \emptyset_2 \end{Bmatrix} \qquad 4.1.6a$$

And where

$$[N] = [N_1 \;\; N_2 \;\; N_3 \;\; N_4] \qquad 4.1.6b$$

And

$$N_1 = \frac{1}{L^3}(2x^3 - 3x^2L + L^3) \qquad N_2 = \frac{1}{L^3}(x^3L - 2x^2L^2 + xL^3) \qquad 4.1.7$$
$$N_4 = \frac{1}{L^3}(-2x^3 + 3x^2L) \qquad N_4 = \frac{1}{L^3}(x^3L - x^2L^2)$$

Integrate the equation 4.1.1h, we get

$$N_i \frac{d}{dx}\left(EI\frac{d^2v}{dx^2}\right) - N_i'\left(EI\frac{d^2v}{dx^2}\right) + \int N_i EI\frac{d^2v}{dx^2}\,dx \qquad 4.1.8$$

The integration by part shows that the highest order is on 3rd order

$$w^{(e)} = a + bx + cx^2 + dx^3 + \cdots \qquad 4.1.9$$

The beam is divided into 2 point which is point 1 and point 2, so from the equation 4.1.9, we get

$$w = a + bx + cx^2 + dx^3 \qquad 4.1.10$$

$$w' = b + 2c + 3dx^2$$

$$w_1 = a$$

$$w_2 = a + bh + ch^2 + dh^3$$

$$w' = b$$

$$w_2' = b + 2ch + 3dh^2$$

In form of matrix, equation 4.1.10 will become

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & h & h^2 & h^3 \\ 0 & 1 & 2h & 3h^2 \end{bmatrix} \begin{Bmatrix} a \\ b \\ c \\ d \end{Bmatrix} = \begin{Bmatrix} w_1 \\ w'_1 \\ w_2 \\ w'_2 \end{Bmatrix} = [A]\{a\}\{v\} \qquad 4.1.11$$

So,

$$\{a\} = [A]^{-1}\{v\}$$

Shown earlier that,

$$\int_0^h N_i(x) \frac{d^2}{dx^w} (EI \frac{d^2 v}{dx^2}) + \rho A \left(\frac{\partial^2 v}{\partial t^2} \right) - F - F_0 \delta(x - x_0) dx = 0 \qquad 4.1.12$$

Therefore,

$$\int_0^h N''_i(x)\left(EI\frac{d^2v}{dx^2}\right)dx \tag{4.1.13}$$

$$+\int_0^h \rho A\{N\}[F+F_0\delta(x-x_0)dx$$

$$=-\begin{Bmatrix} N_1\left(EIv^{(e)''}\right)'\Big|_0^h \\ N_2\left(EIv^{(e)''}\right)'\Big|_0^h \\ N_3\left(EIv^{(e)''}\right)'\Big|_0^h \\ N_4\left(EIv^{(e)''}\right)'\Big|_0^h \end{Bmatrix}+\begin{Bmatrix} N'_1\left(EIv^{(e)''}\right)'\Big|_0^h \\ N'_2\left(EIv^{(e)''}\right)'\Big|_0^h \\ N'_3\left(EIv^{(e)''}\right)'\Big|_0^h \\ N'_4\left(EIv^{(e)''}\right)'\Big|_0^h \end{Bmatrix}$$

$$+\int_0^h \{N\}[F+F_0\delta^A(x-x_0)dx$$

$$\int_0^h \rho A\{N\}[N]dx\{\ddot{v}\}^{(ne)}+\int_0^h \rho A\{N''\}[N'']dx\{v\}^{(ne)} \tag{4.1.14}$$

$$=\begin{pmatrix} s_1 \\ 0 \\ -s_2 \\ 0 \end{pmatrix}+\begin{pmatrix} 0 \\ -M_1 \\ 0 \\ M_2 \end{pmatrix}+\int_0^h \{N\}[F+F_0\delta(x-x_0)]dx$$

$$v^{(e)}=[N]\{v\}^{(ne)}$$

$$S_1=(EIv^{(e)''})'\Big|_{x=0}$$

By assuming that the first function in equation 4.1.14 as [M] and second function as [k]. Thus,

$$[M]^{(e)}\{\ddot{v}\}^{(ne)}+[k]\{v\}^{(ne)}=\{P\}^{(ne)}+\begin{Bmatrix} -S_1 \\ -M_1 \\ S_2 \\ M_2 \end{Bmatrix} \tag{4.1.15}$$

$$[k]^{(e)}=\int_0^h EI\begin{Bmatrix} N''_1 \\ N''_2 \\ N''_3 \\ N''_4 \end{Bmatrix}^{(ne)}+\{N''_1\ \ N''_2\ \ N''_3\ \ N''_4\}\,dx \tag{4.1.16}$$

$$[k]^{(e)} = \int_0^h \frac{EI}{l^3} \begin{bmatrix} N_1^2 & N_1N_2 & N_1N_3 & N_1N_4 \\ N_2N_1 & N_2^2 & N_2N_3 & N_2N_4 \\ N_3N_1 & N_3N_2 & N_3^2 & N_3N_4 \\ N_4N_1 & N_4N_2 & N_4N_3 & N_4^2 \end{bmatrix} \quad 4.1.17$$

$$[k]^{(e)} = \int_0^h \frac{EI}{l^3} \begin{bmatrix} 12 & 6l & -12 & 6l \\ & 4l^2 & -6l & 2l^2 \\ & & 12 & -6l \\ sym & & & 4l^2 \end{bmatrix} \quad 4.1.18$$

When the femur is fixed at the point v_1 will be zero. Thus the equation will be,

$$[k]^{(e)} = \frac{EI}{l^3} \begin{bmatrix} 12 & -6l \\ -6l & 4l^2 \end{bmatrix} \quad 4.1.19$$

Knowing that the formula for force is $F = kx$, so we rewrite back the equation 4.1.19, we get

$$\left[\frac{F}{x}\right]^{(e)} = \frac{EI}{l^3} \begin{bmatrix} 12 & -6l \\ -6l & 4l^2 \end{bmatrix} \quad 4.1.20$$

Where the force will be the distribution force used, E will be the modulus of elasticity, and the length of ACL will be 0.103m.

4.7.2 Numerical Validation using Galerkin Analysis

By using the equation 4.1.20,

$$\left[\frac{F}{x}\right]^{(e)} = \frac{EI}{l^3} \begin{bmatrix} 12 & -6l \\ -6l & 4l^2 \end{bmatrix} \quad 4.1.20$$

From the data that we get form previous journal, we will calculate the values for error using the equation 4.1.20

Table 4.1: Data used for Calculation

Data	Value
Distribution Force	474N, 768N, 909N and 977N
Modulus of Elasticity, E	11000 MPa (ACL)
Length, l	0.103m
Moment of Inertia, I	2.1627e-8m^4

Sample calculation for 371N force,

$$\begin{Bmatrix} 371 \\ 0 \end{Bmatrix} = \frac{EI}{l^3}\begin{bmatrix} 12 & -6l \\ -6l & 4l^2 \end{bmatrix}\begin{Bmatrix} v_2 \\ \emptyset_2 \end{Bmatrix}$$

$$\begin{Bmatrix} 371 \\ 0 \end{Bmatrix} = \frac{(11x10^9)(2.1627x10^{-6})}{(0.103)^3}\begin{bmatrix} 12 & -6(0.103) \\ -6(0.103) & 4(0.103)^2 \end{bmatrix}\begin{Bmatrix} v_2 \\ \emptyset_2 \end{Bmatrix}$$

$$\begin{Bmatrix} 371 \\ 0 \end{Bmatrix} = 21.77x10^6[12v_2]$$

$$v_2 = 1.42x10^{-6}$$

Table 4.2: Percentages Error between Calculation and Without Kneepad Data

Force (N)	**Strain (m/m)**		
	Calculation	**Without Kneepad**	**Percentages Error**
474.5570	$1.82x10^{-6}$	$5.47x10^{-7}$	69.95
767.8874	$2.94x10^{-6}$	$8.85x10^{-7}$	69.90
909.4966	$3.48x10^{-6}$	$1.05x10^{-6}$	69.83
976.5417	$3.74x10^{-6}$	$1.13x10^{-6}$	69.79

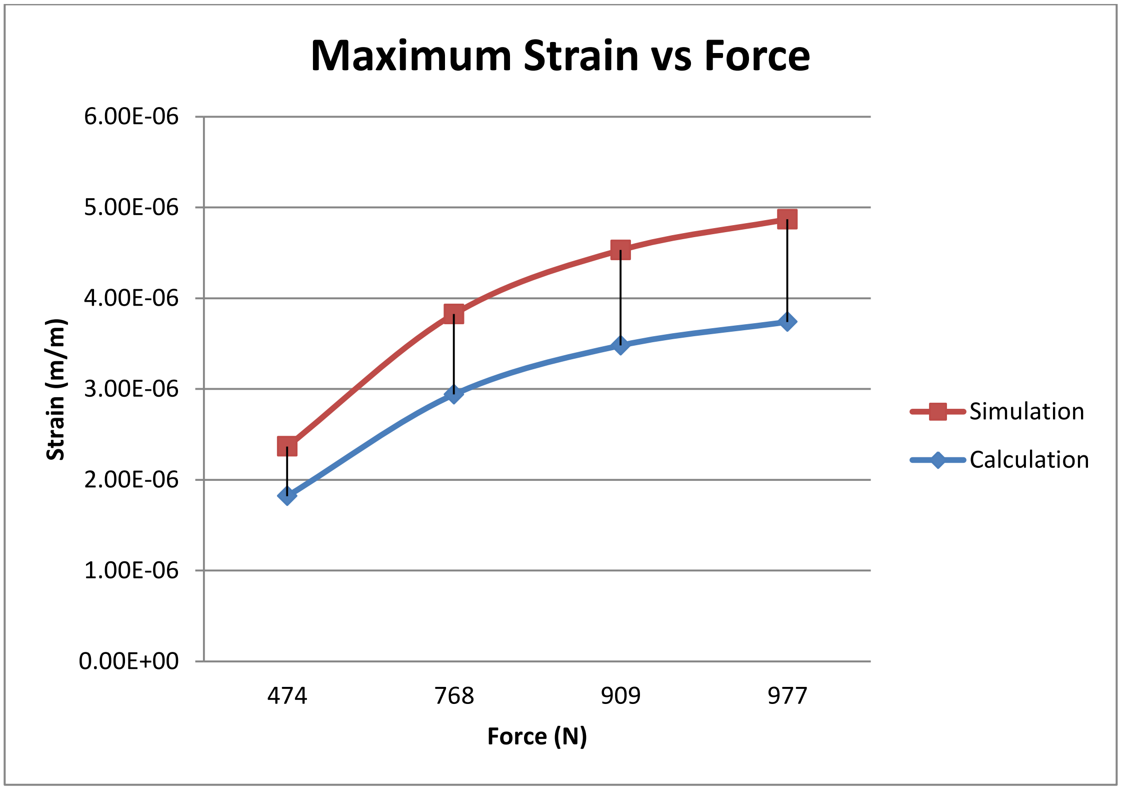


Figure 4.23: Graph of Comparison between Simulation Data and Calculation Data

The table and graph above shows the error analysis between the calculation data and the simulation data. The distribution that used in this study is 474N, 768N, 909N and 977N. The numerical calculation was the values which are retrieved from the equation which is generated from equation 4.1.20.

CHARTER 5

CONCLUSION AND RECOMMENDATION

In this chapter, a conclusion is made which summaries the whole part of this study and also included the suitable recommendation which can be implemented to improve more so that the development and study could help others in many ways. The conclusion of this paper will refer back to the objective of the study where it will discuss whether the target is achieved or not achieved. Besides that, by learning the negative parts of the development, better recommendation could be taken which will improvise the scopes of the study and also the limitations, giving a better result in the future.

5.1 CONCLUSION

In conclusion, the final analysis is presented which follow as the objectives of this paper which is to analyze the ligament behavior for healthy human leg with or without kneepad after kicking the ball activities. For the Finite Element Method simulation result clearly shows that the highest angle flexion that can occur injured is at 90degree flexion. It shows that at this point, the ligament is so sensitive with its environment. Any wrong step, injury can occur.

For the first and second knee model, the result is still the same. The highest stress values occur at the 90degree flexion. It is because of the condition of the ligament itself. The ligament at this point has reached its final twisting stage. After this point, the ligament will not twisting anymore, but it will start to bend until it reach a bending limit.

The kneepad that is suitable to be used by the football player is the knee pad that possess the characteristics of absorbing force like the saw dusk, because it will not causing the pain to the user when the ball came in contact with the kneepad, but this does not mean that the kneepad that has the resisting force characteristics is not good, just because it is not suitable for being used in the football games as it will cause pain to the users knee when came in contact with the force from the ball.

In order to reduce the rate of the injuries to the football player, the kneepad used must have a suitable materials used inside it, because the less the deformation of the material used, the higher the ultimate tensile strength of the material, and thus will these material will have a strength to withstand the impact force that came in contact to its body.

Other than that, the kneepad used also must have a suitable size, so that it can fit well to the users knee during they are using it in their sports activities, because if the size does not fit the user’s knee, the kneepad will not giving enough and proper protection to the ligament of the user and thus the user will exposed their knee to the injuries.

Besides, the kneepad used also must have the good air ventilation system in order to prevent the user from abrasion. The air ventilation system is important also in order to give a best comfort for the user to wear the kneepad during their sports activities.

5.2 RECOMMENDATIONS

As for the recommendation, it is known that the current subject used is only male subject. Therefore, it better if the subject for this kind of study will also include the female player also. It is because female player strength is not the same with the male player. So by doing both of this categories, the comparison between this categories can be done and it also can approve which categories have the highest possibility to injured will playing the football activities.

By using more force distribution also one of the recommendation that can be done. It is because by using more high force, the highest strain of the ligament itself can be identified, so it easy for the footballer to avoid the force that can ensure them to get injuries.

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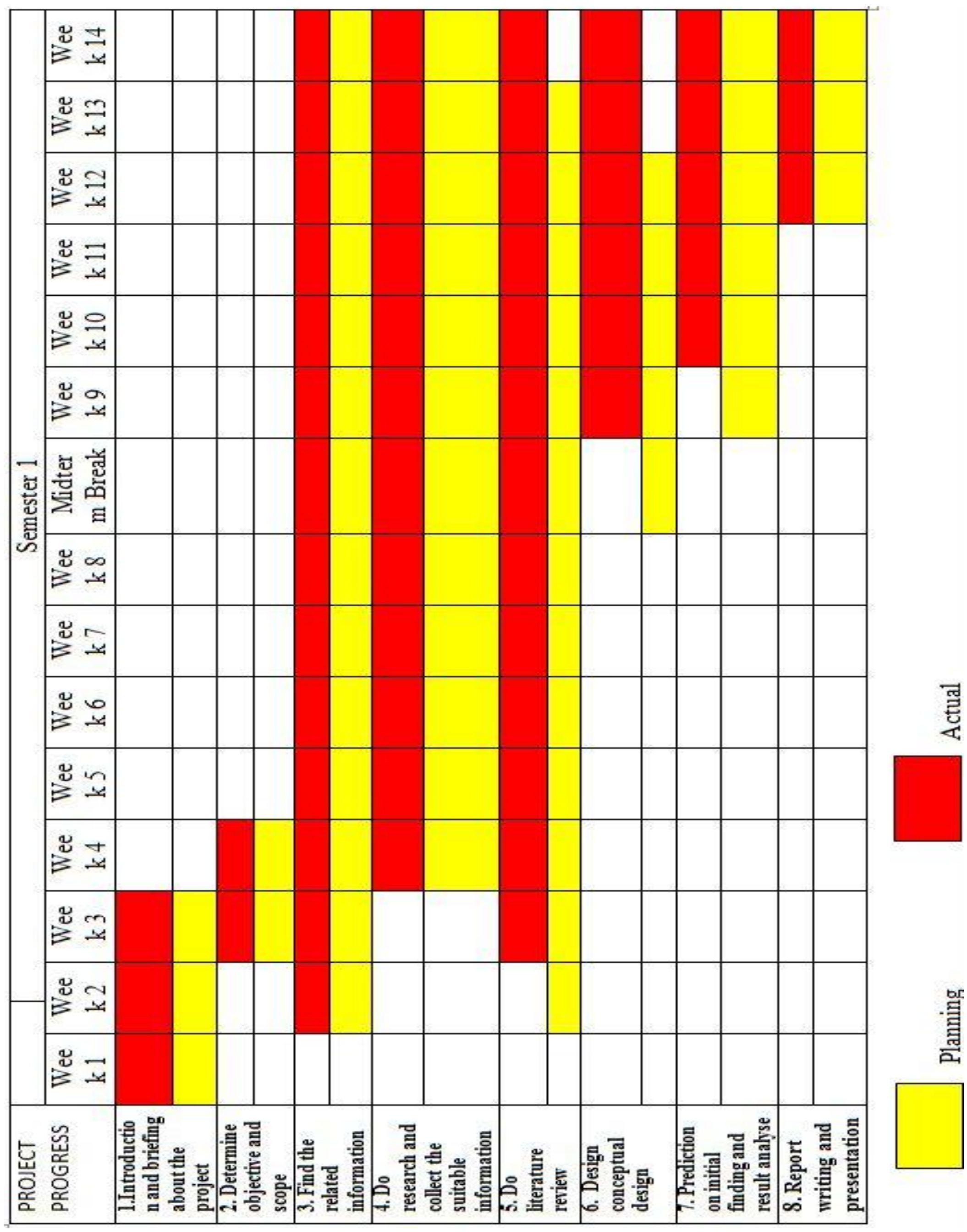
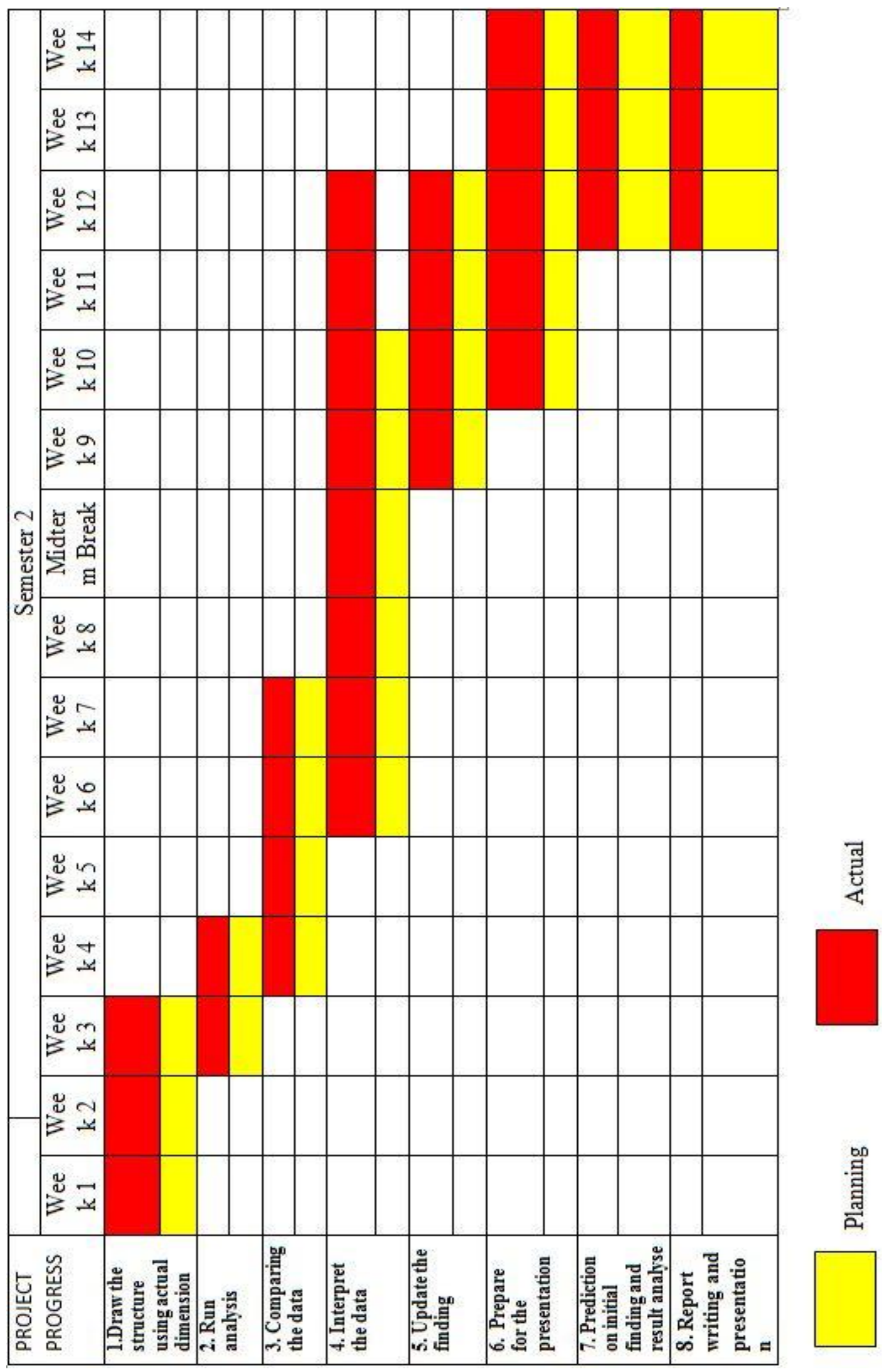
APPENDICES

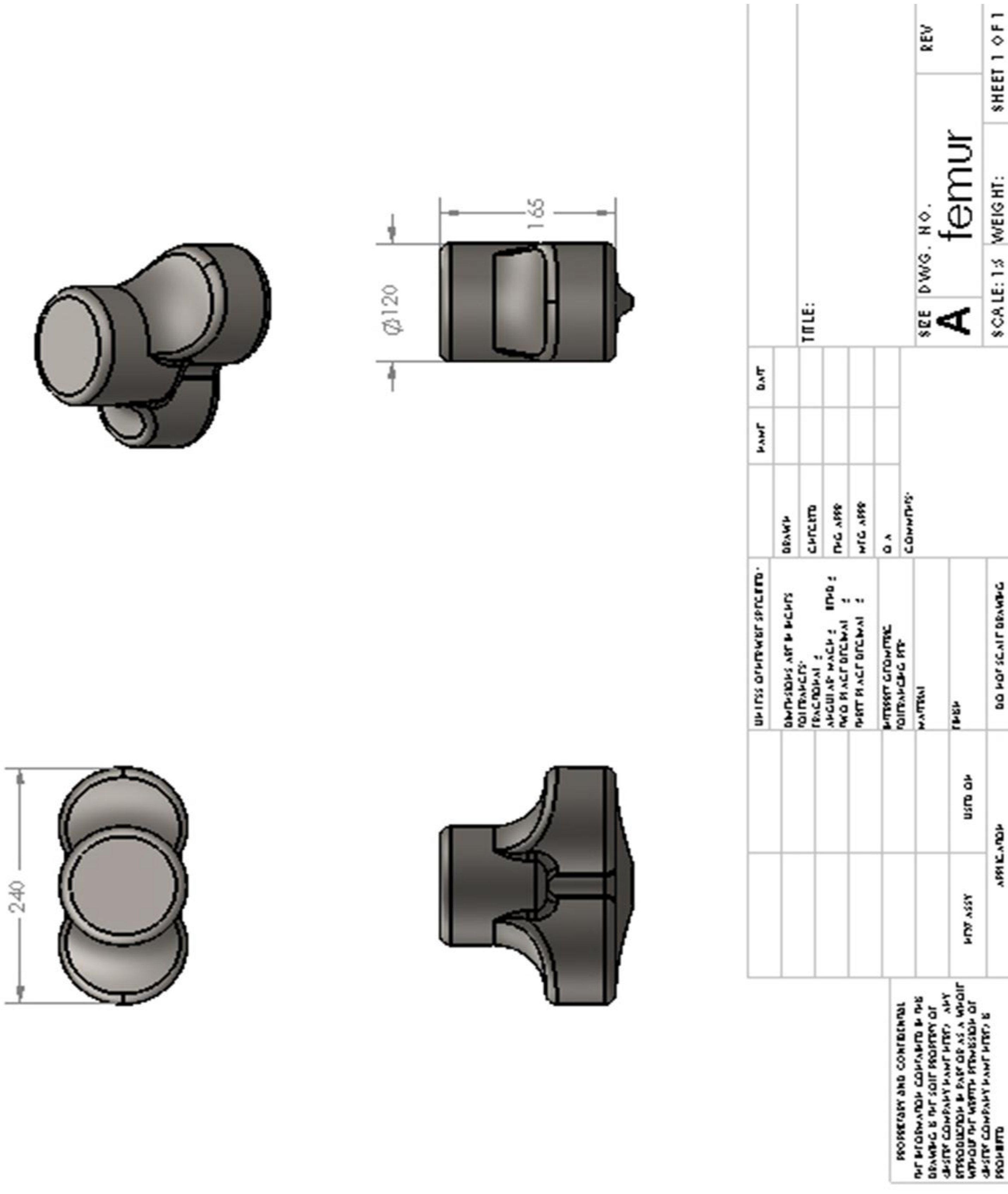
Appendix A- Gantt Chart for Semester 1

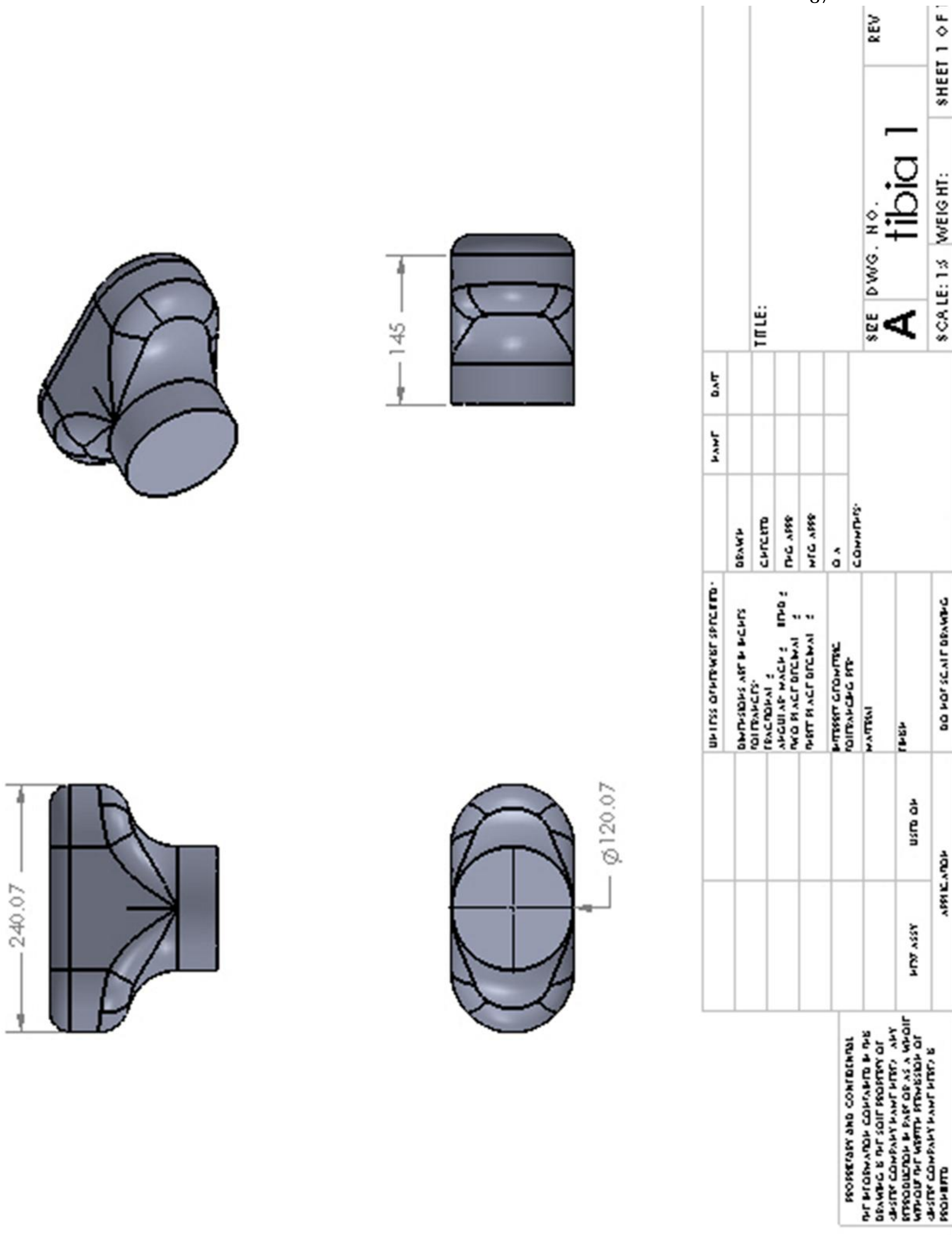


Appendix B- Gantt Chart for Semester 2



Appendix C- SolidWork Design

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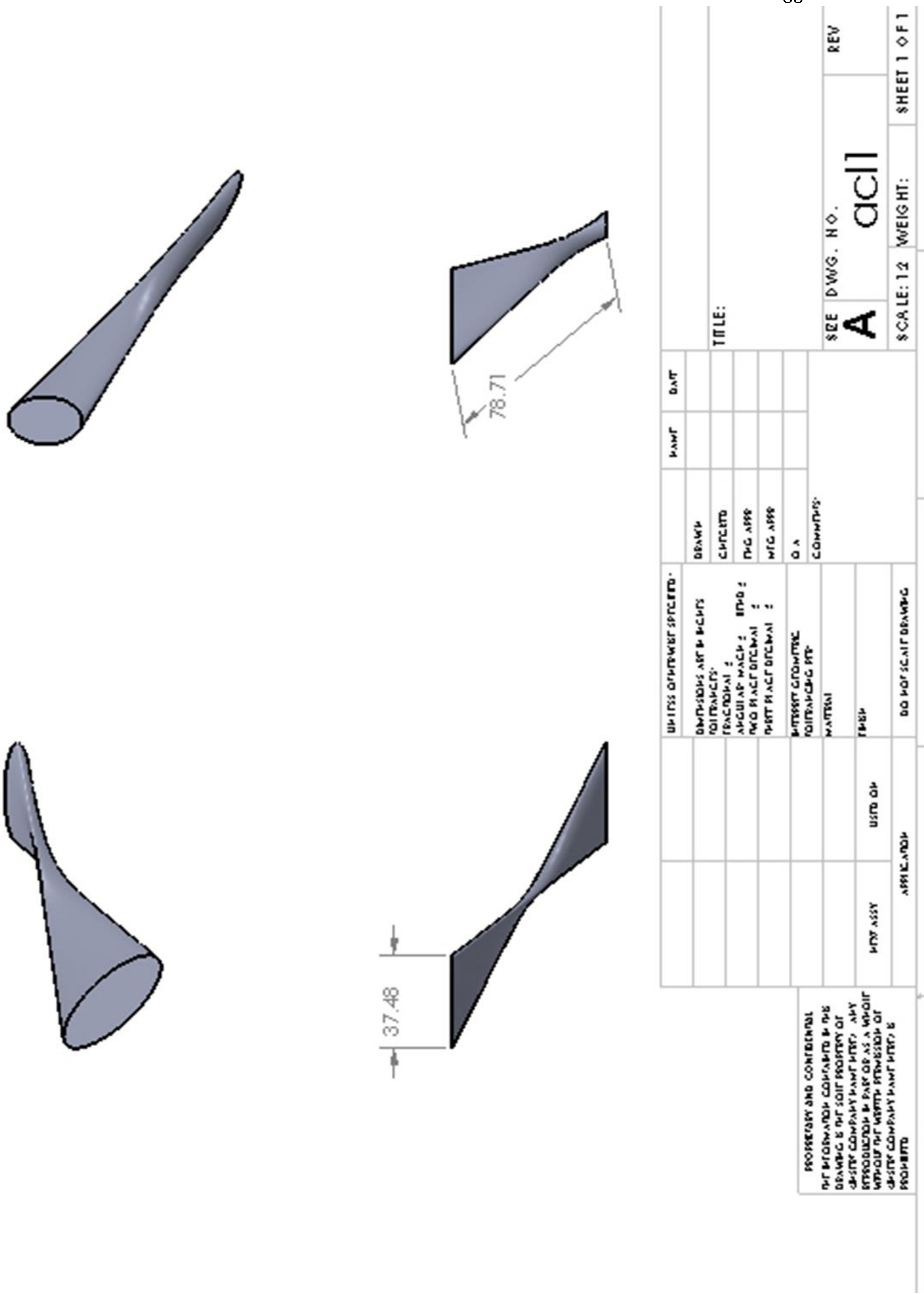
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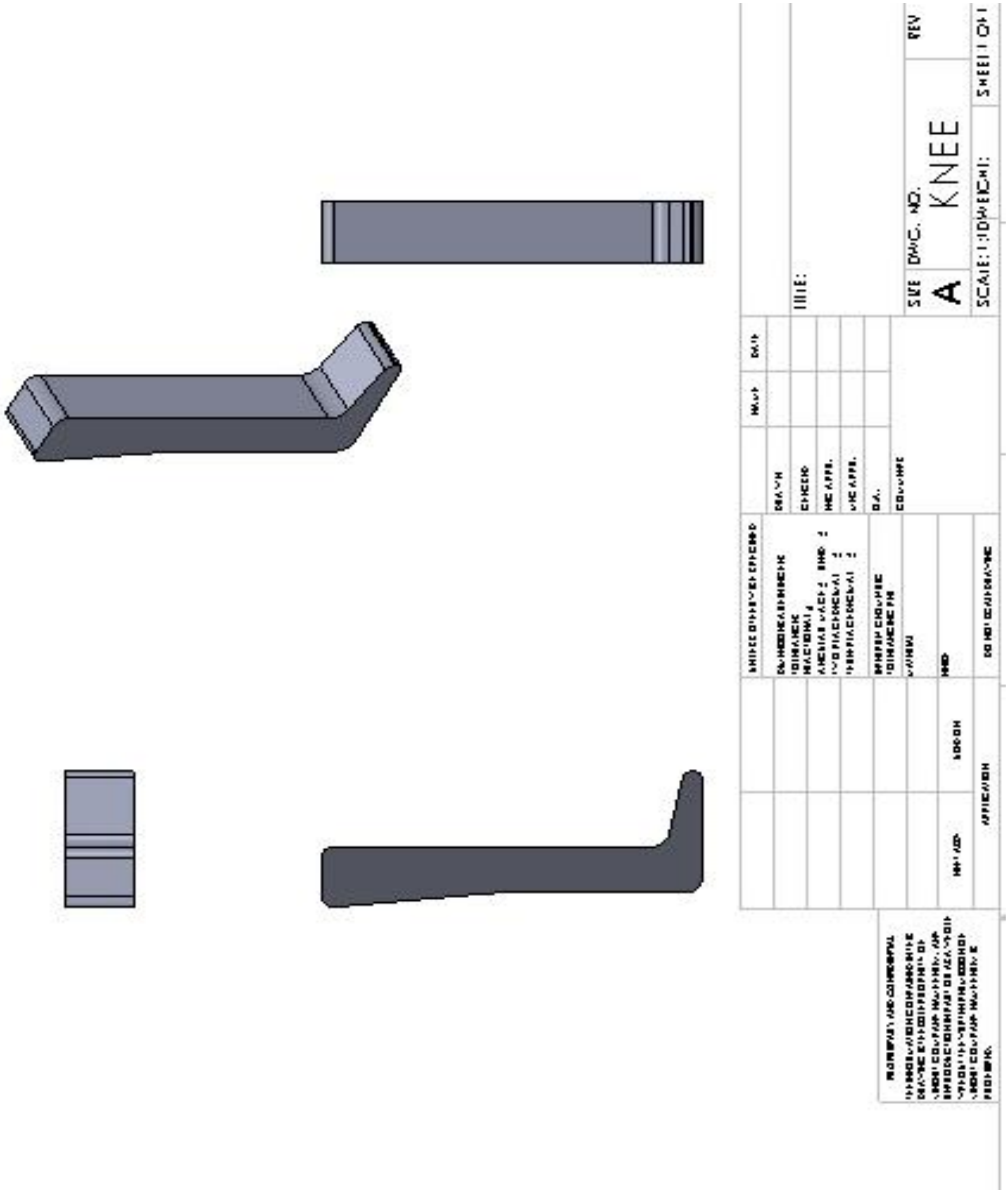
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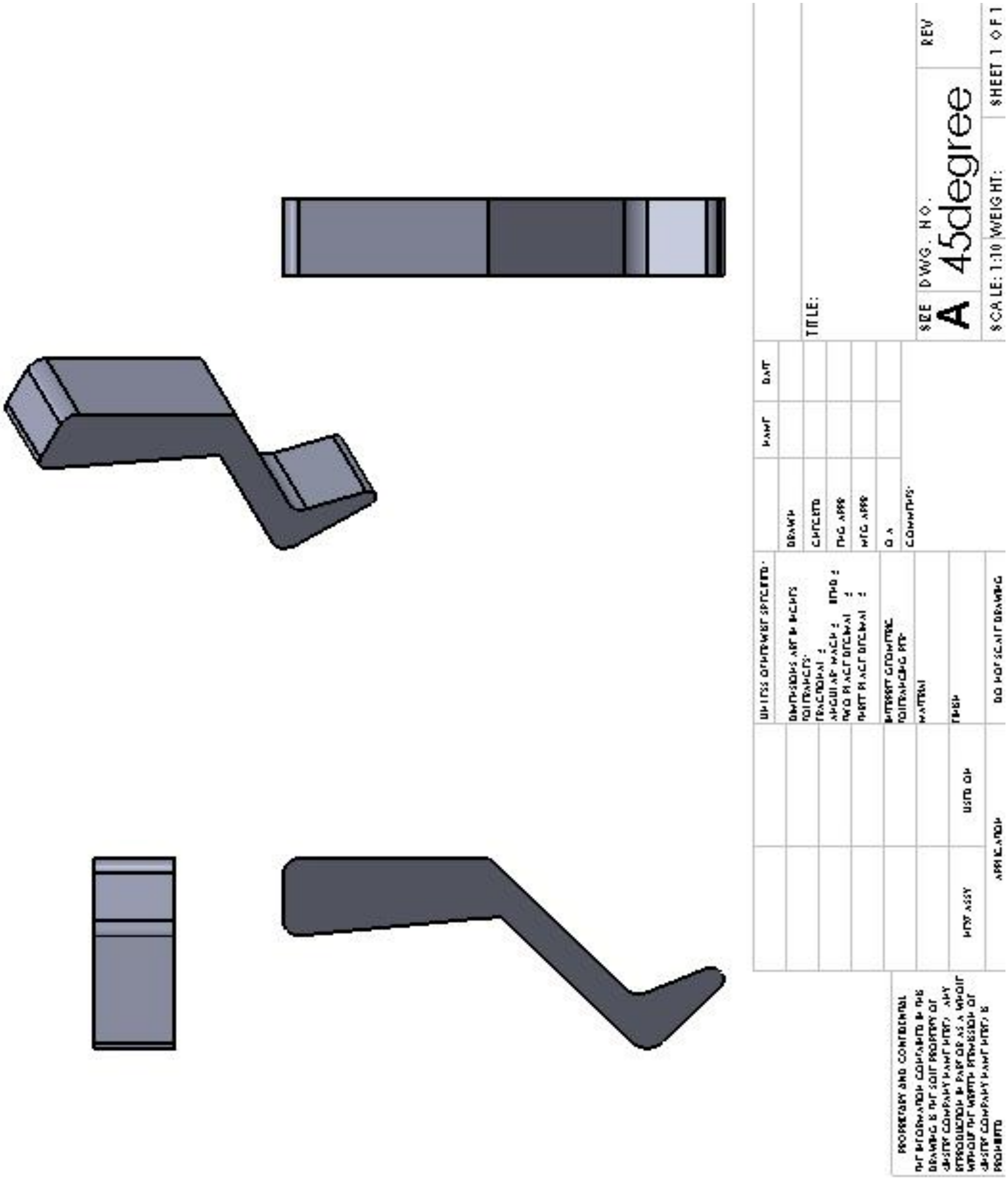
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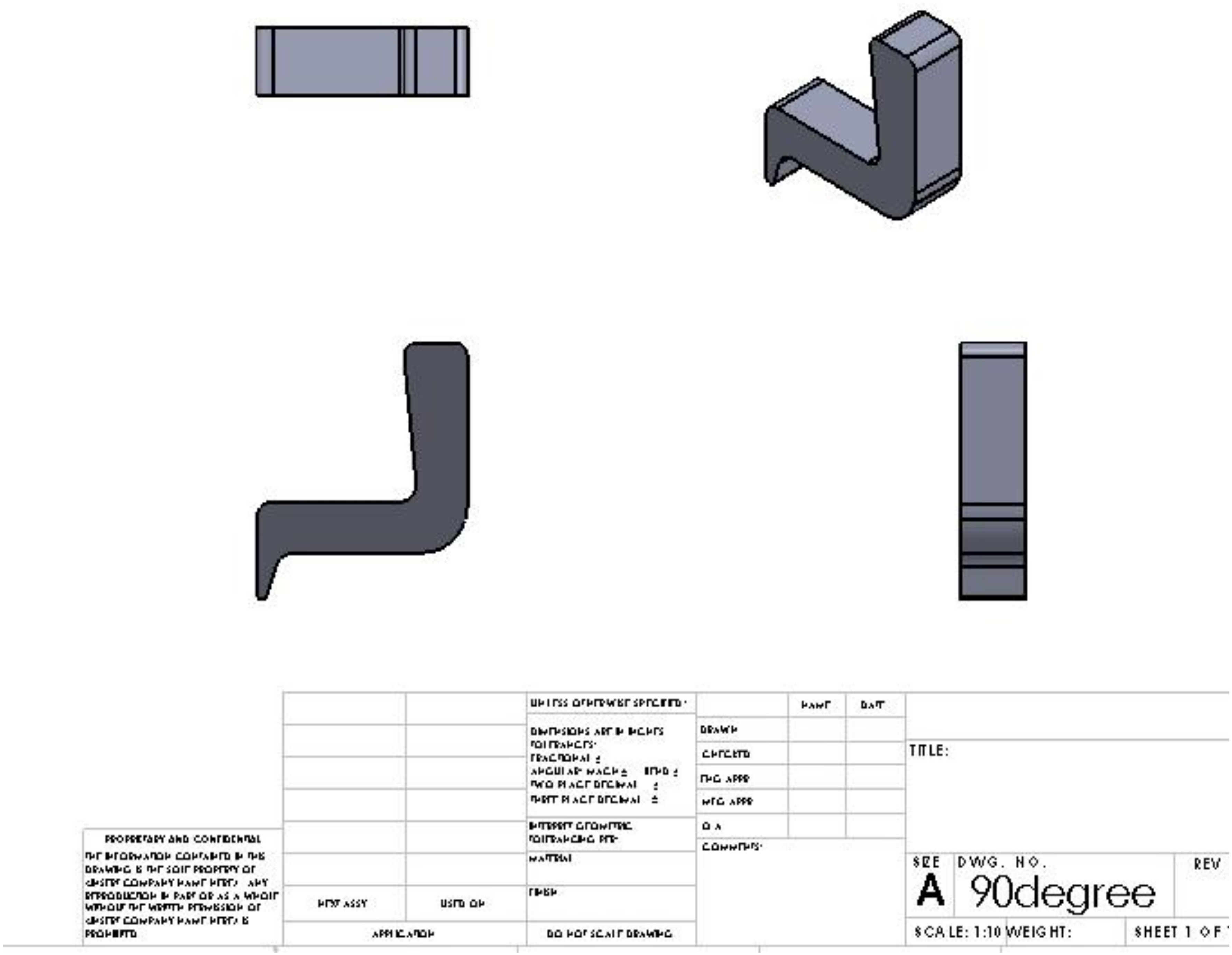
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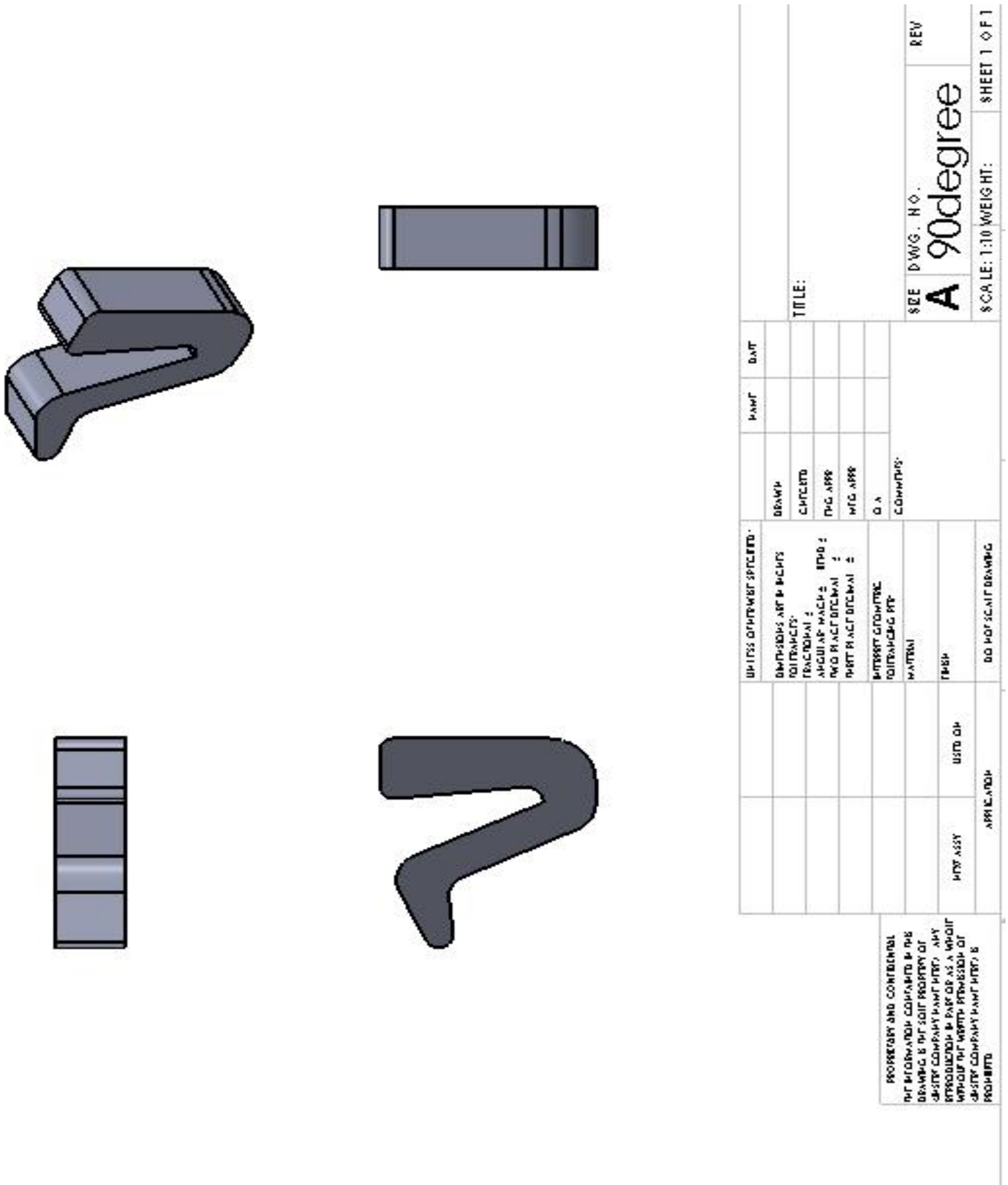
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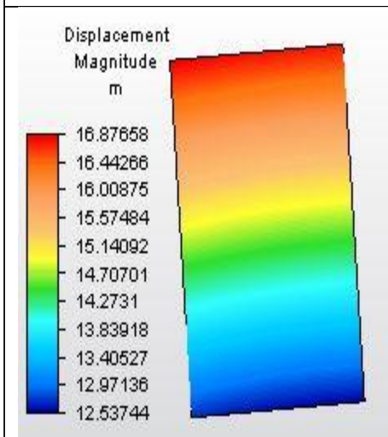
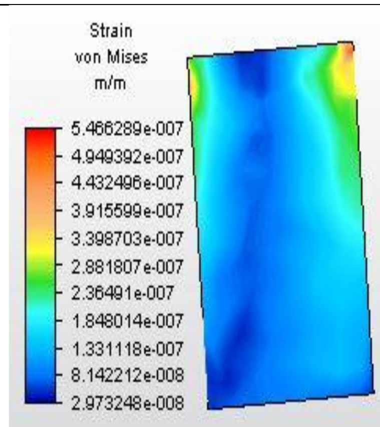
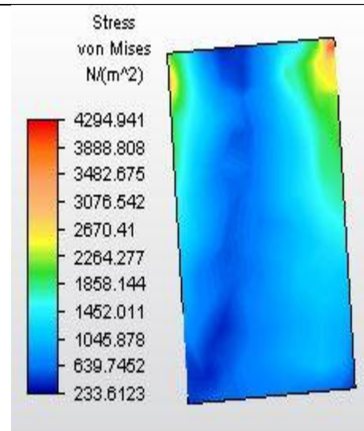
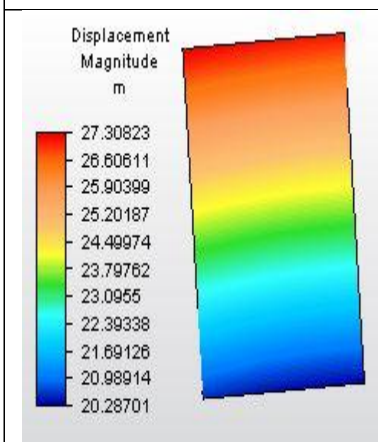
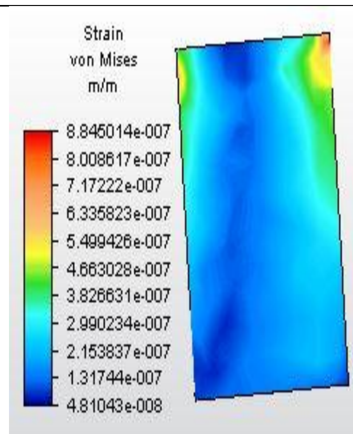
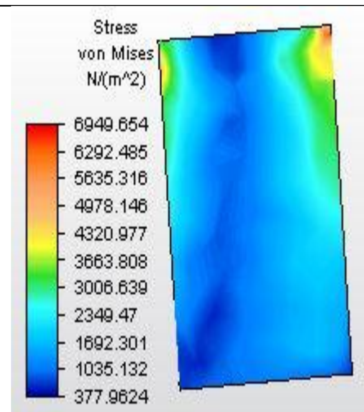
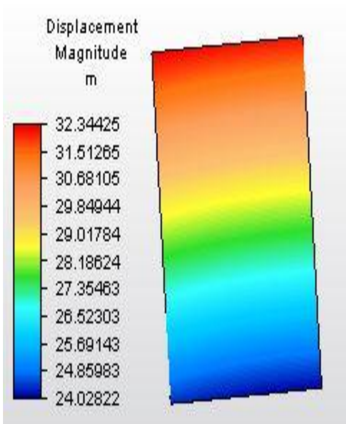
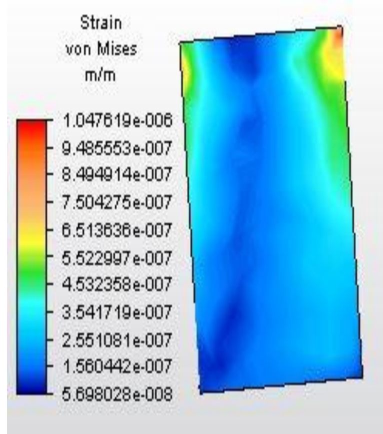
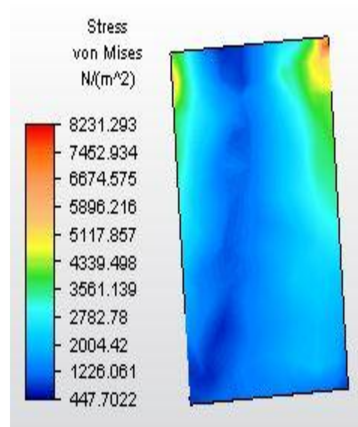
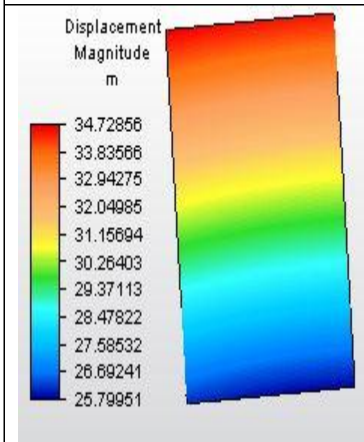
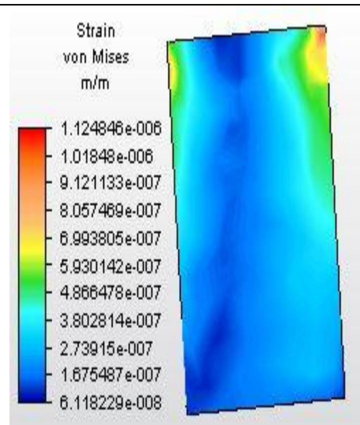
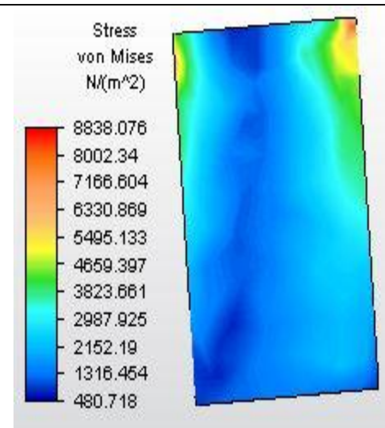
Appendix D- AutoDesk Simulation Result

The simulation result when not applying the kneepad

0degree of flexion		
Force distribution 474.5570N		
		
Displacement	Strain	Stress
Force distribution 767.8874N		
		
Displacement	Strain	Stress

Force distribution 909.4966N		
		
Displacement	Strain	Stress
Force distribution 976.5417N		
		
Displacement	Strain	Stress

<table>
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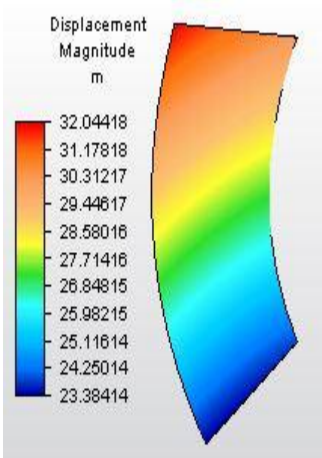
<td>
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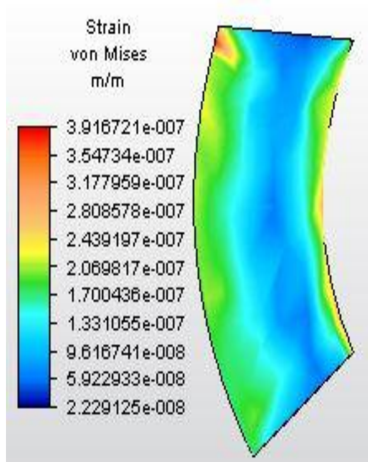
<td>
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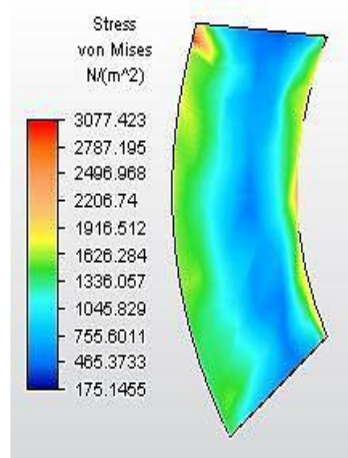
<td>
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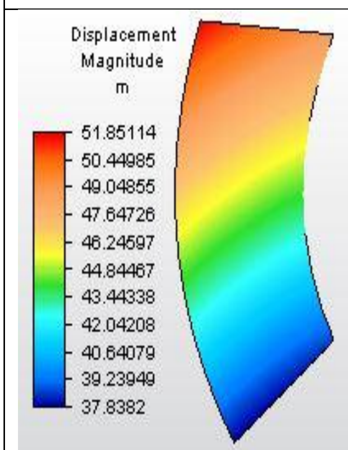
<td>
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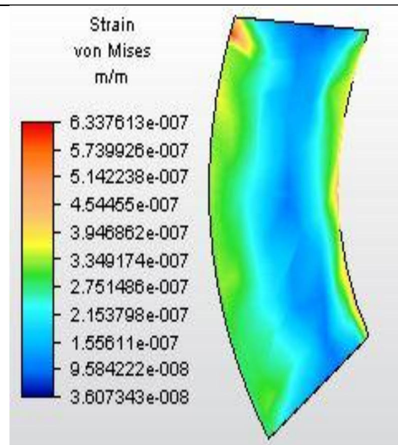
<td>
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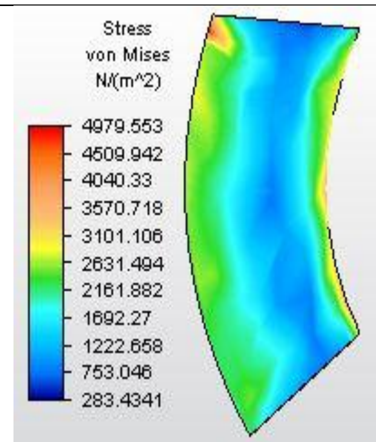
<td>
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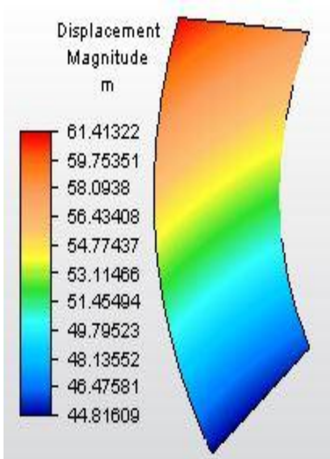

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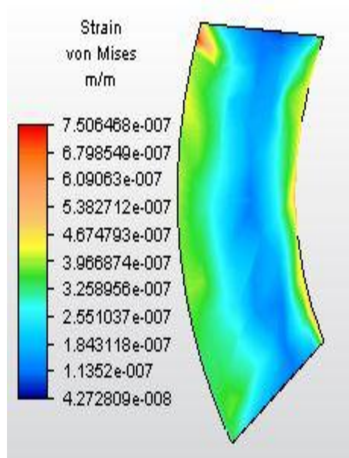

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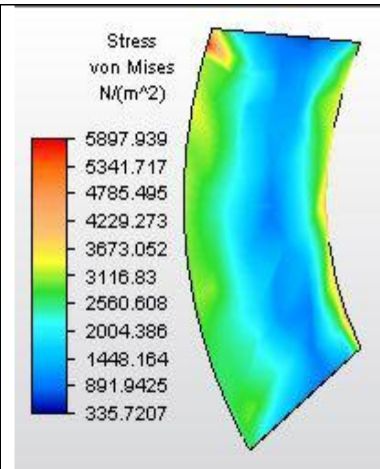

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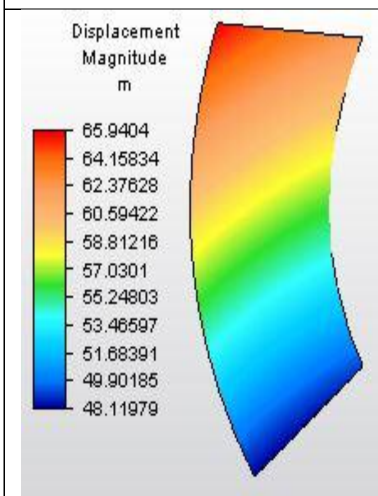

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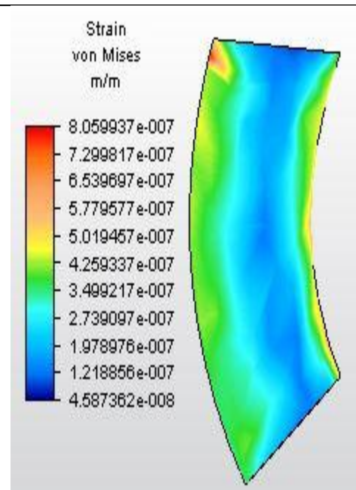

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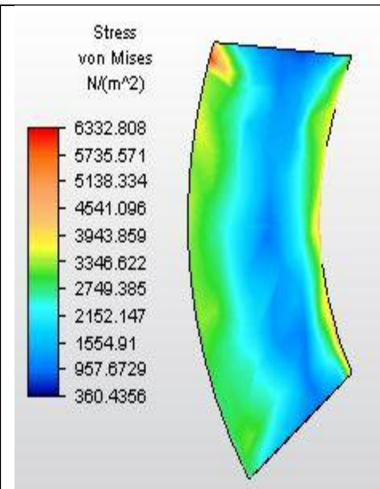

Stress

90degree of flexion		
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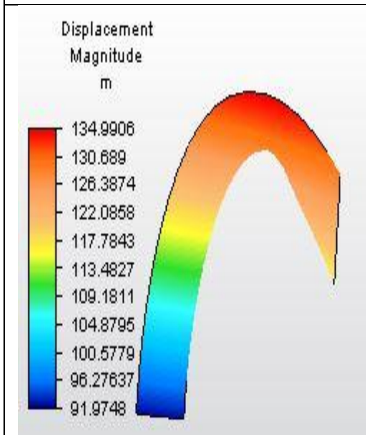	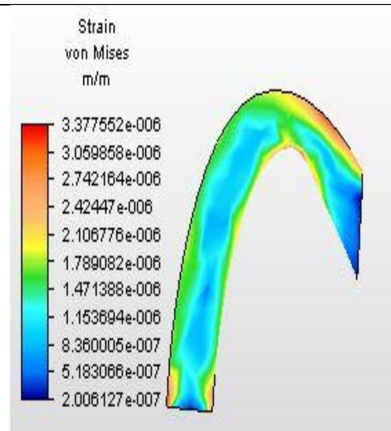	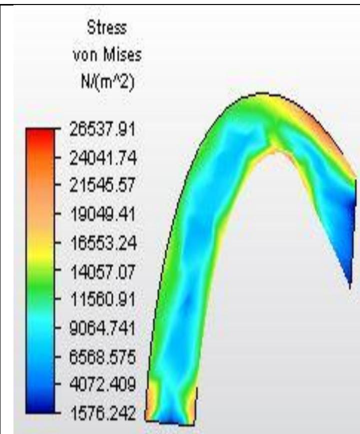
Displacement	Strain	Stress
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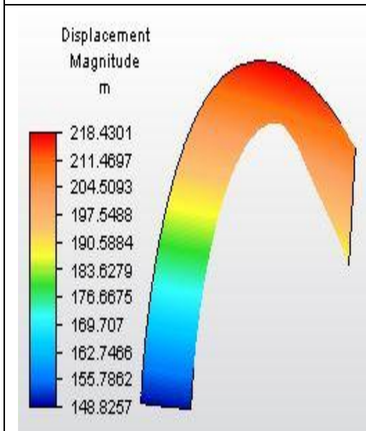	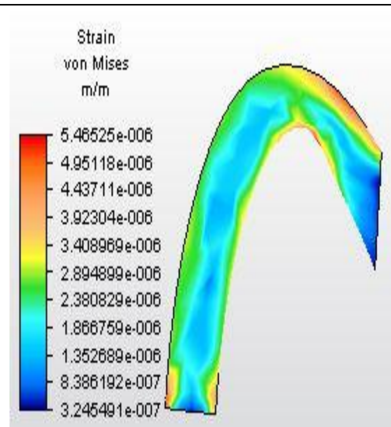	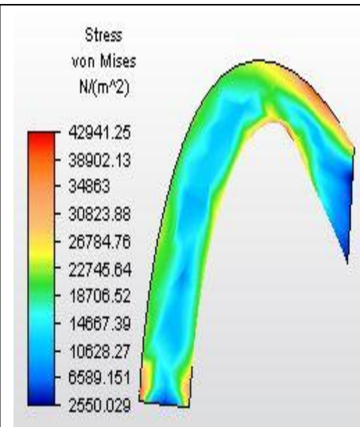
Displacement	Strain	Stress

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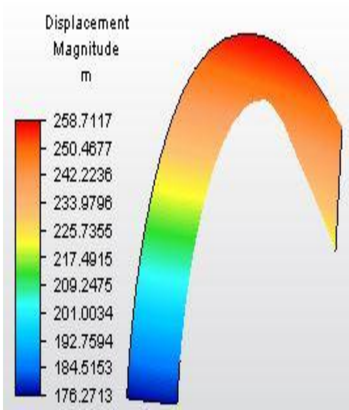
<td>
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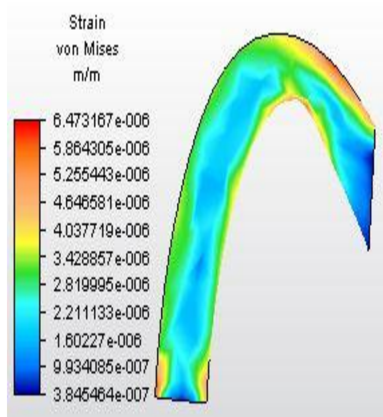
<td>
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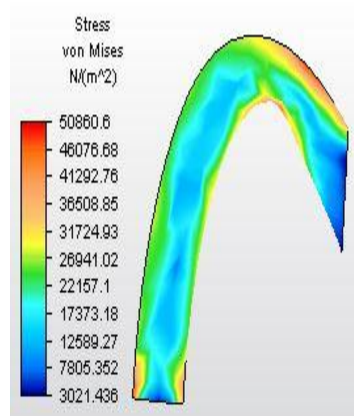
<td>
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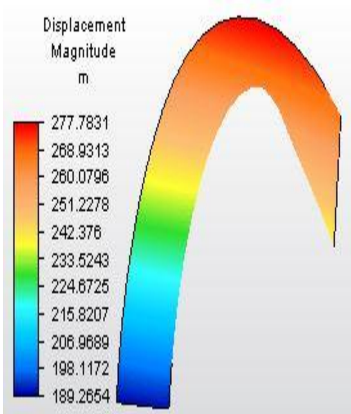
<td>
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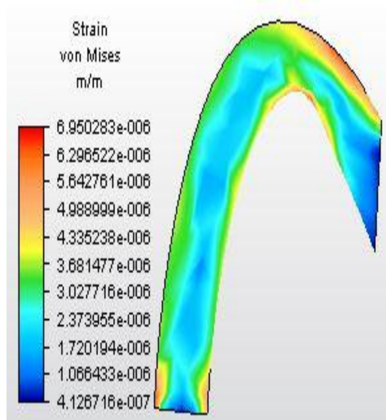
<td>
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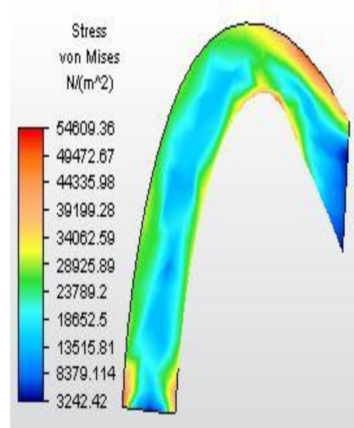
<td>
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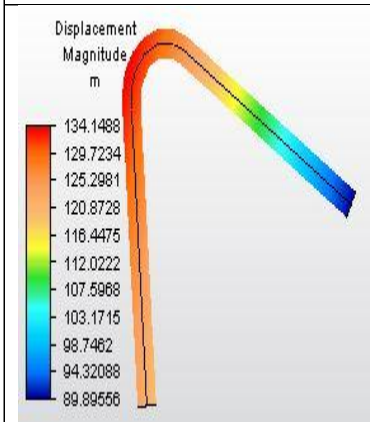
<td>
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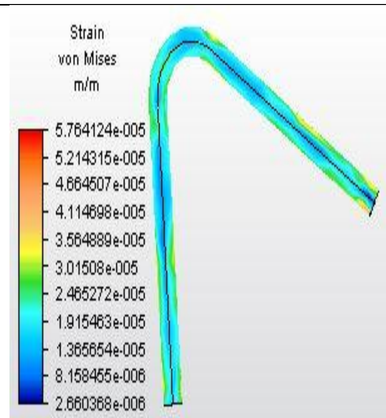
<td>
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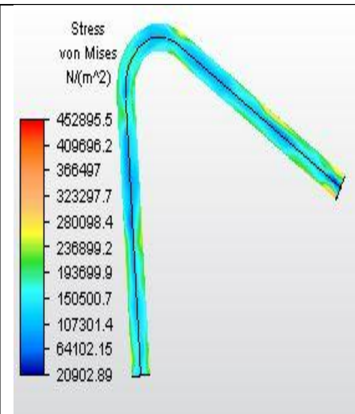
<td>
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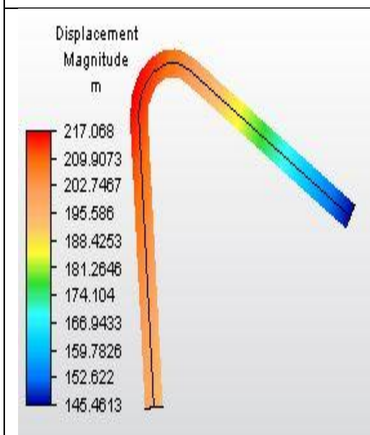
<td>
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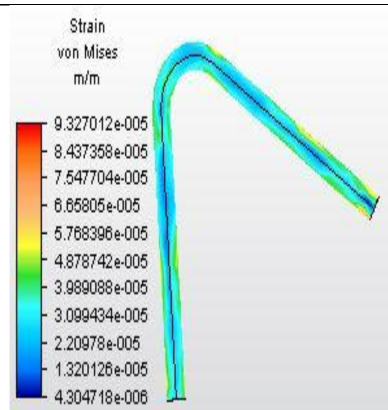
<td>
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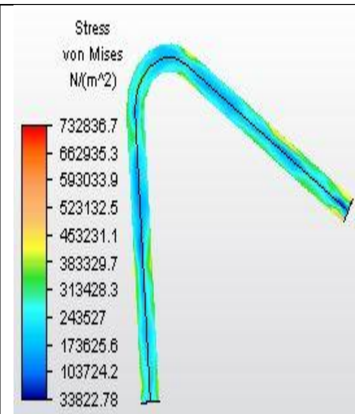
<td>
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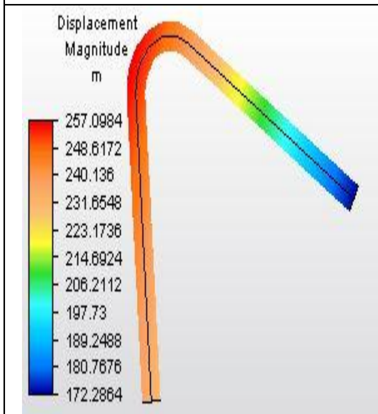
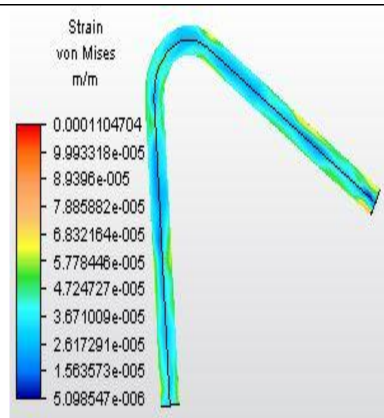
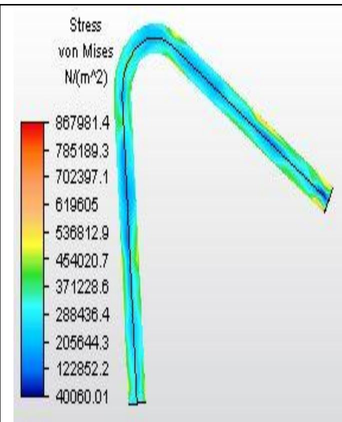
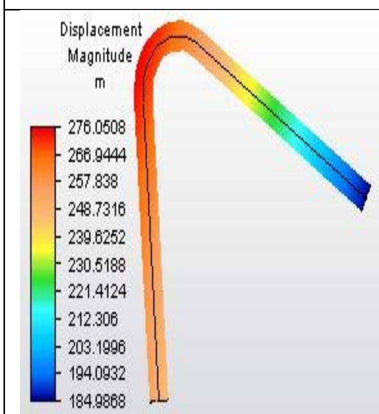
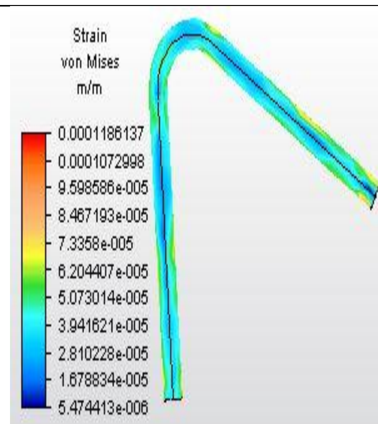
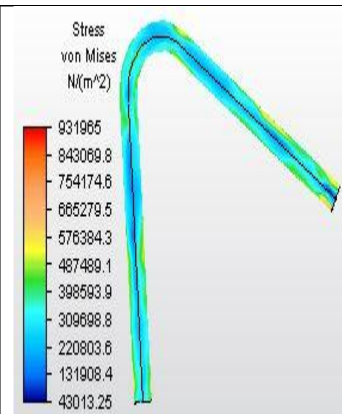
Force distribution 909.4966N		
		
Displacement	Strain	Stress
Force distribution 976.5417N		
		
Displacement	Strain	Stress

The simulation result when applying the kneepad

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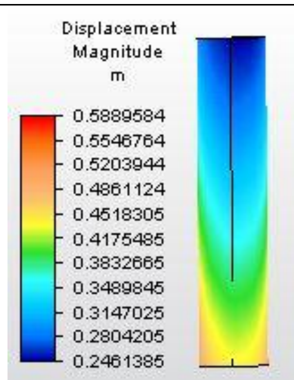
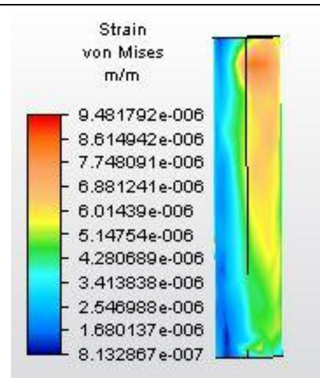
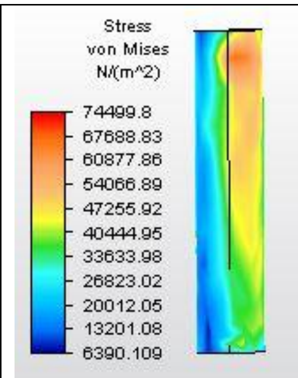
<tr><td>
</td><td>
</td><td>
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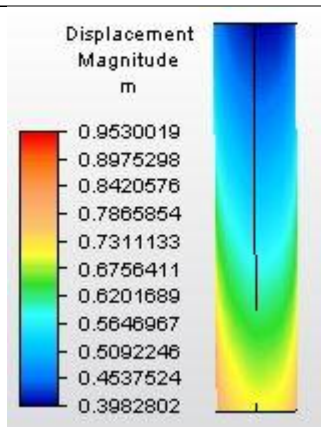
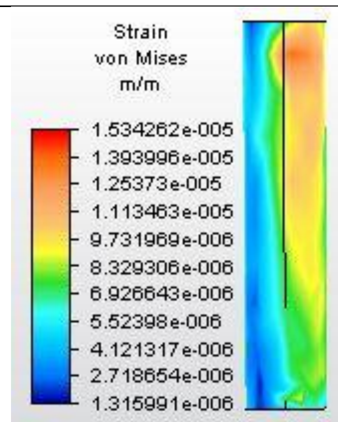
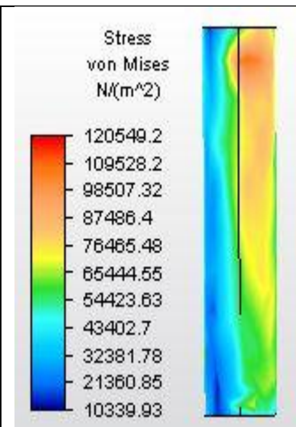
<tr><td>
</td><td>
</td><td>
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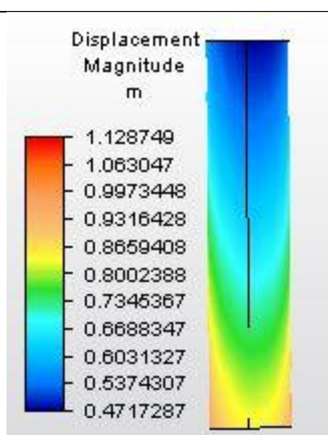
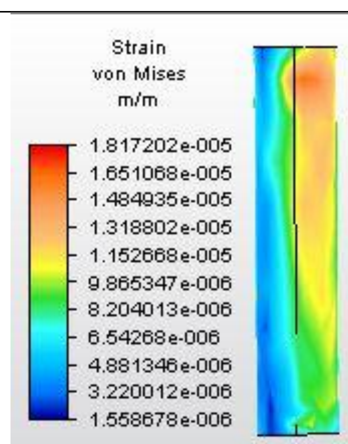
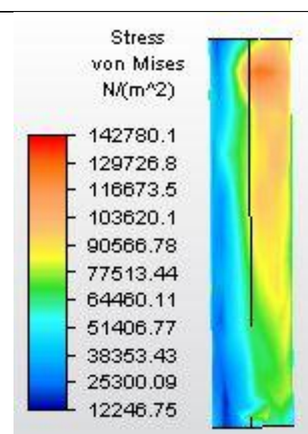
<tr><td>
</td><td>
</td><td>
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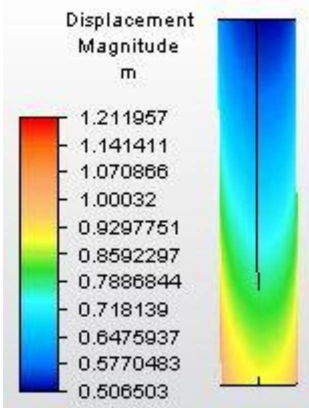
<td>
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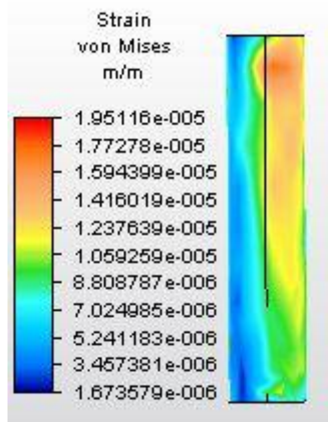
<td>
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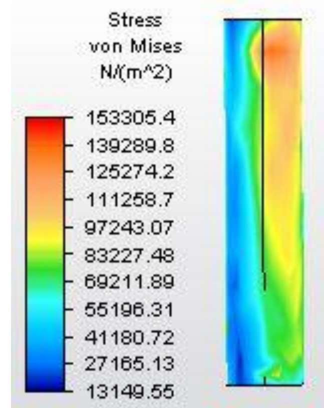
<td>
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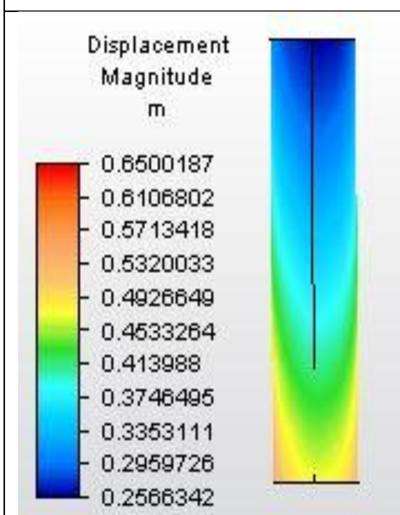
<td>
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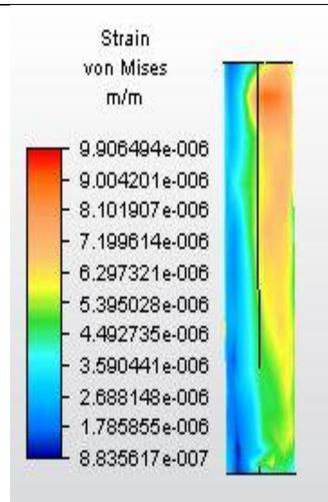
<td>
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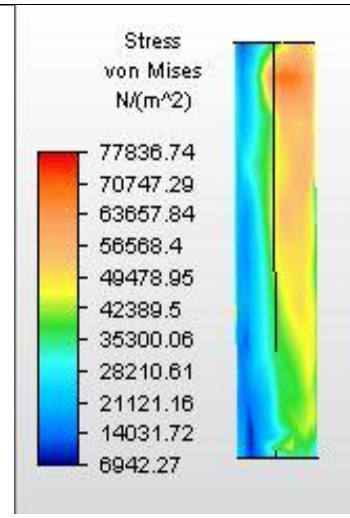
<td>
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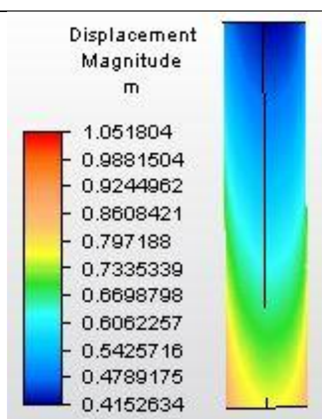
<td>
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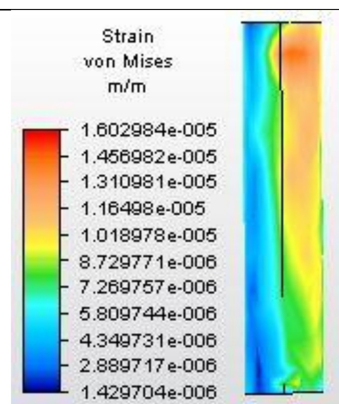
<td>
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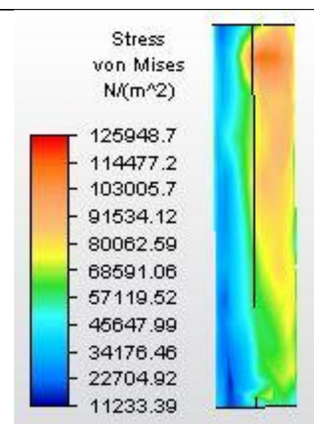
<td>
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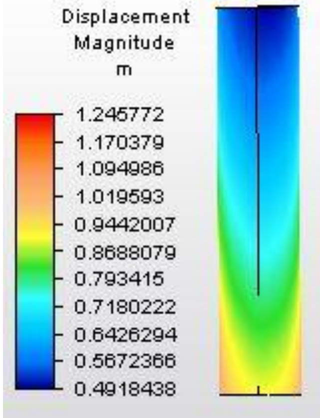
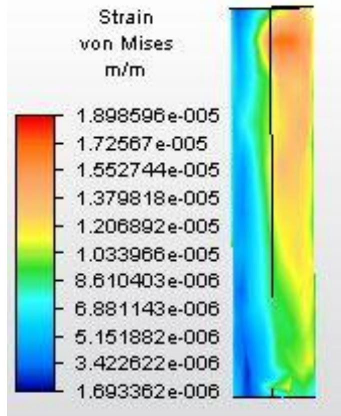
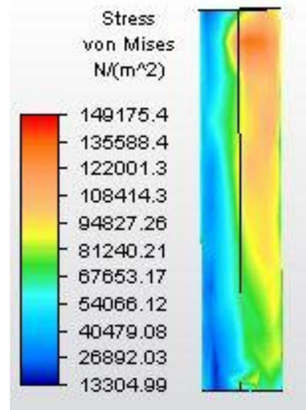
Force distribution 909.4966N







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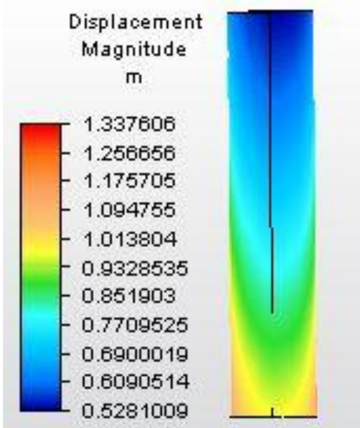
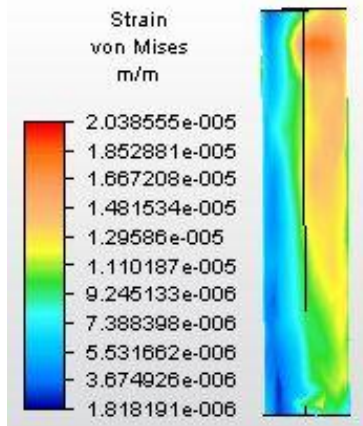
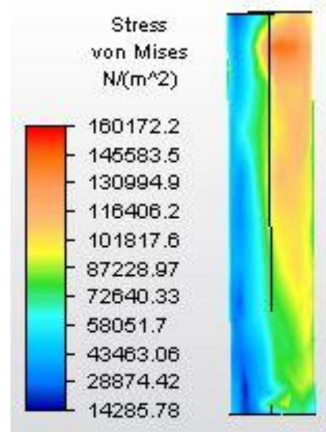
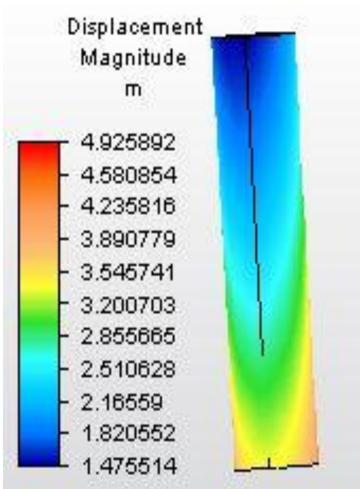


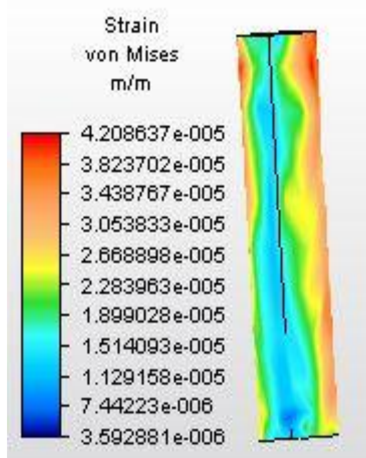


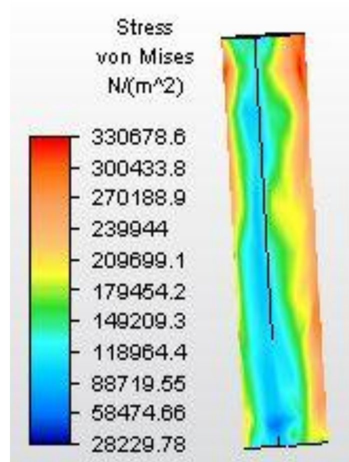


0degree of flexion for Palm Oil kneepad

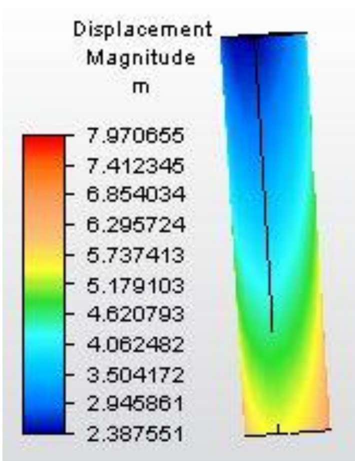
Force distribution 474.5570N

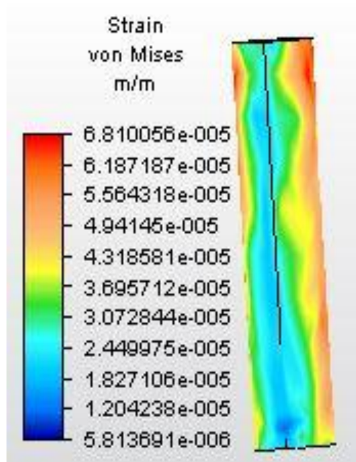


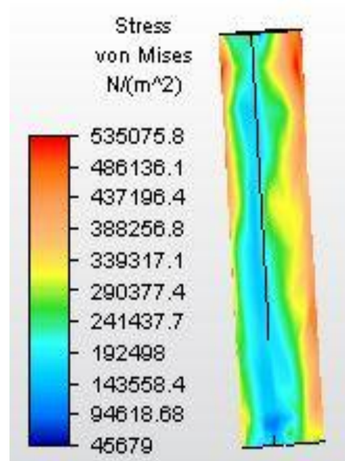




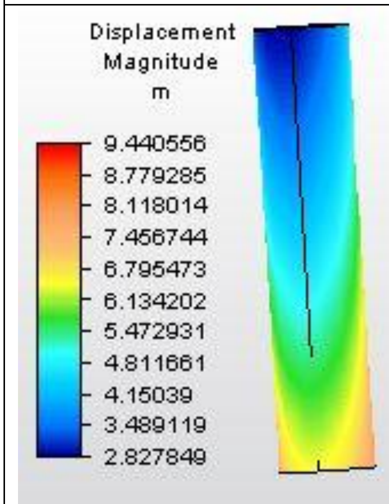
Force distribution 767.8874N

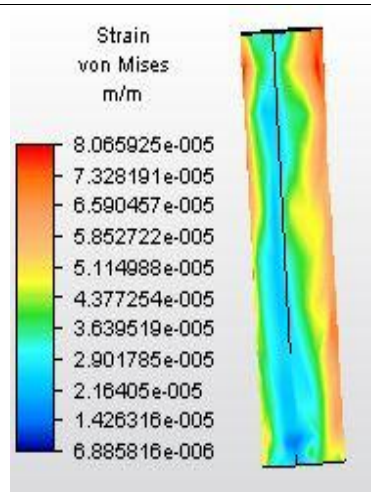


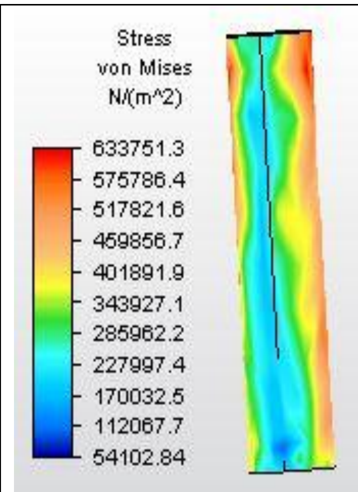




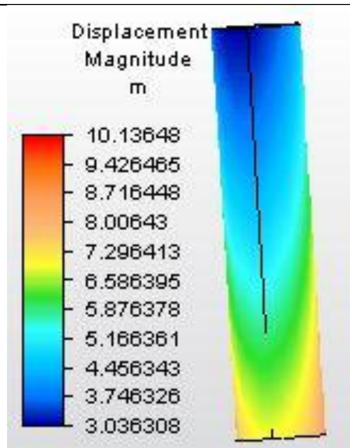
Force distribution 909.4966N

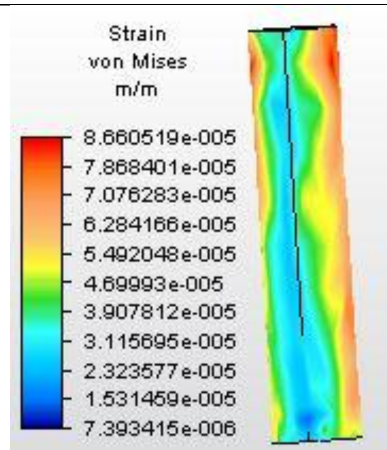


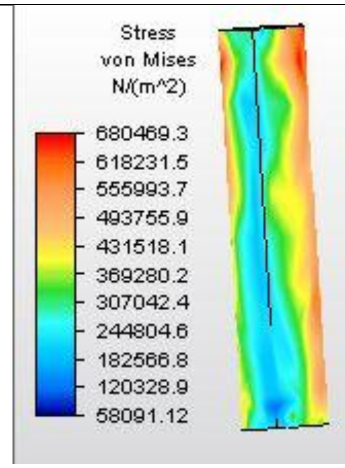




Force distribution 976.5417N







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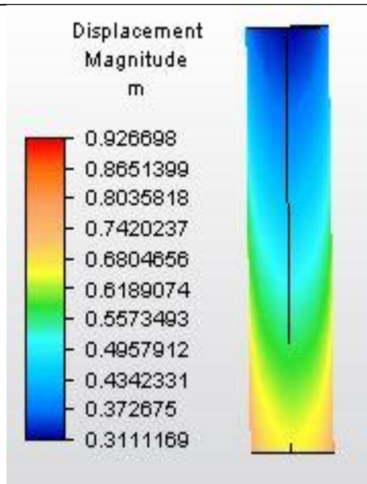
<td>
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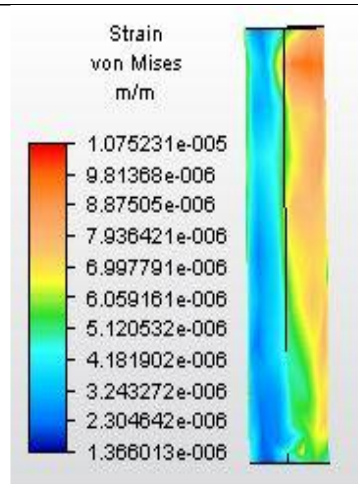
<td>
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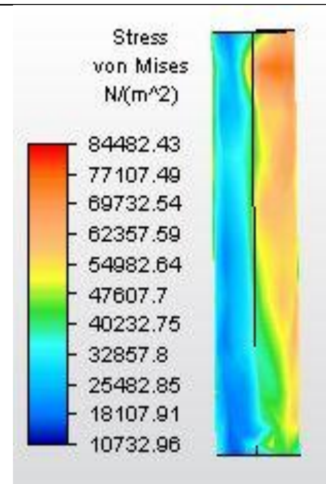
<td>
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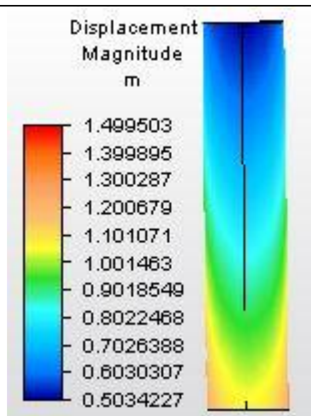
<td>
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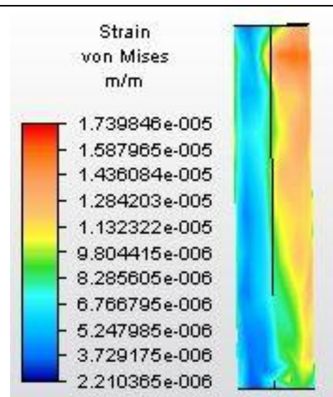
<td>
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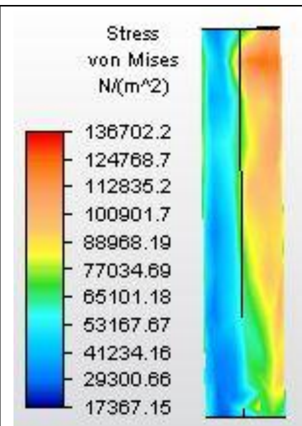
<td>
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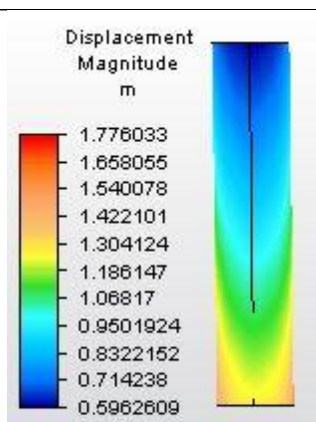
<td>
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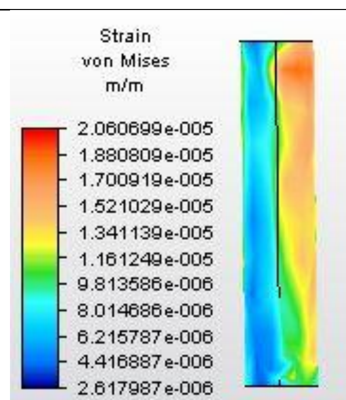
<td>
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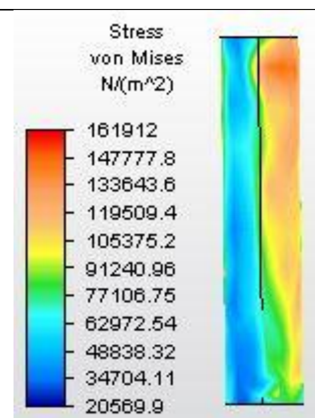
<td>
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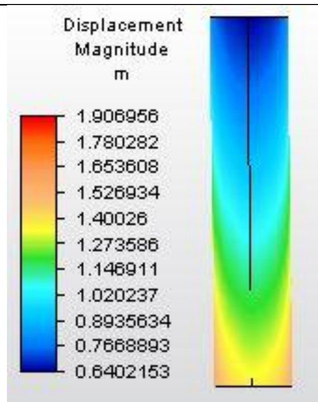
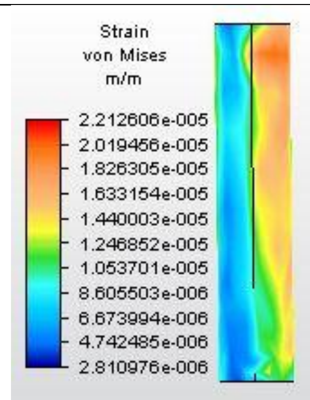
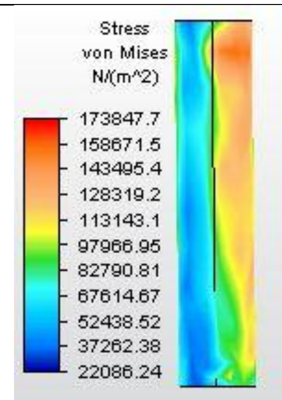
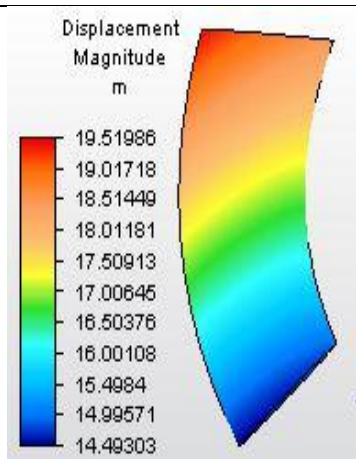


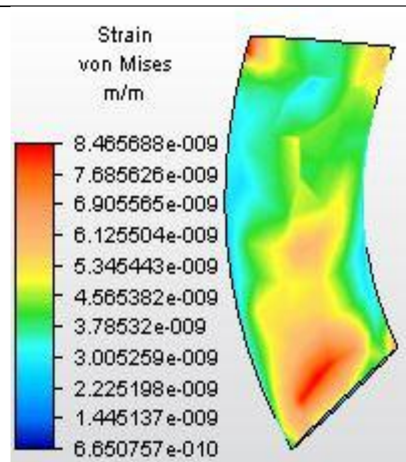


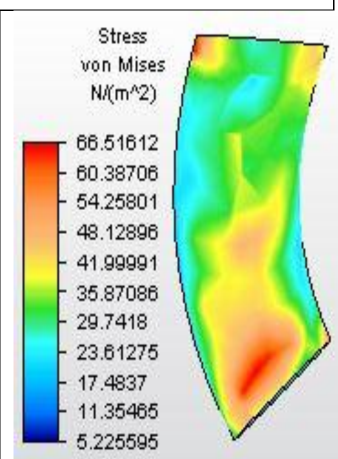


45degree of flexion for kenaf kneepad

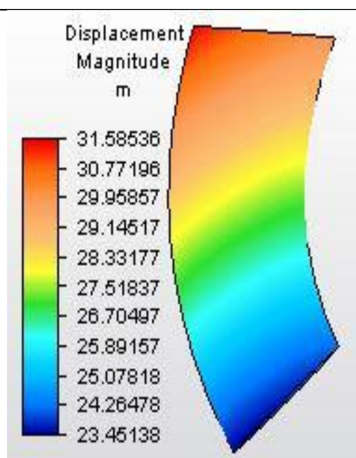
Force distribution 474.5570N

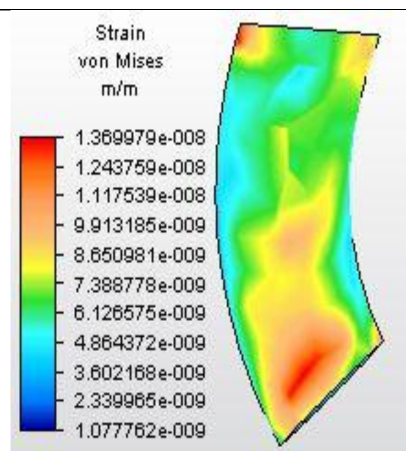


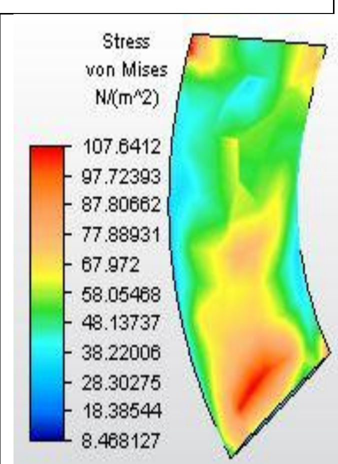




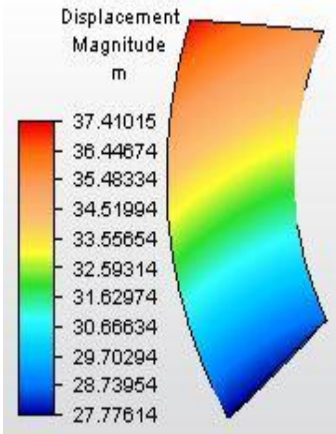
Force distribution 767.8874N

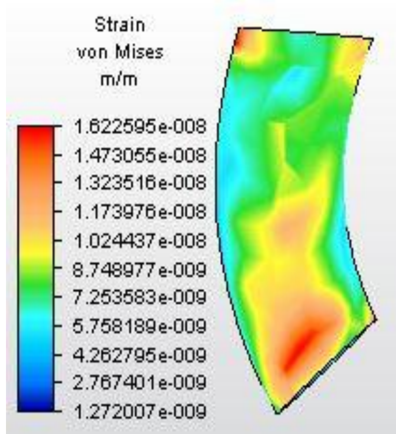


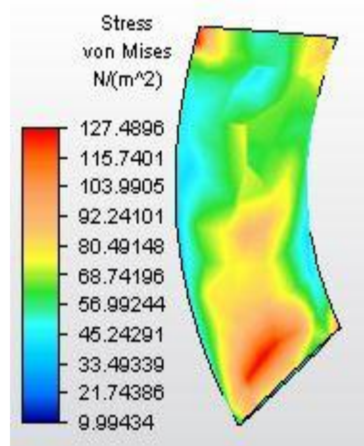




Force distribution 909.4966N







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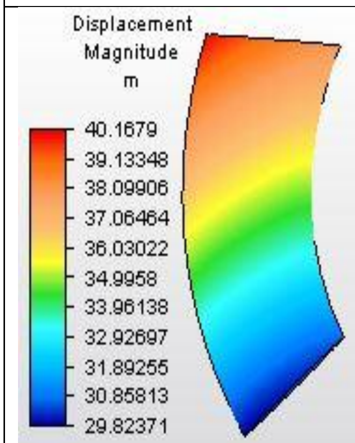
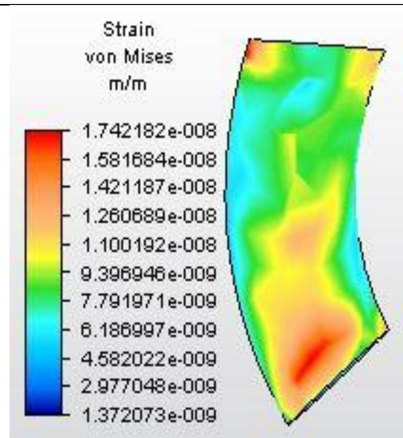
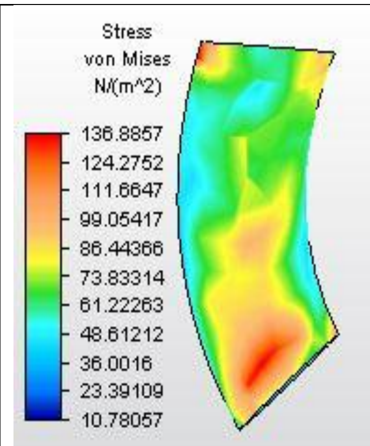
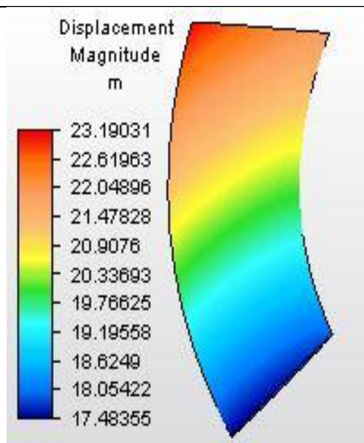


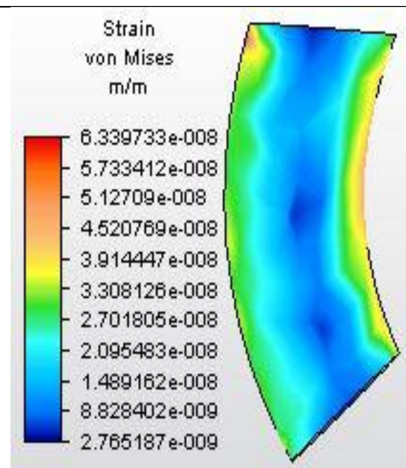


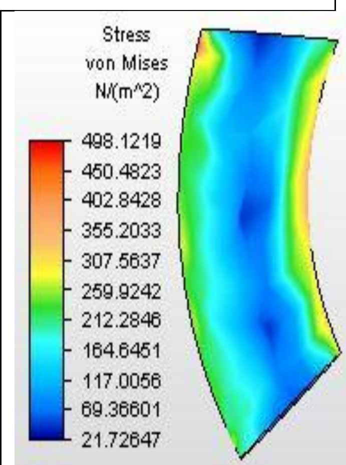


45degree of flexion for Coconut kneepad

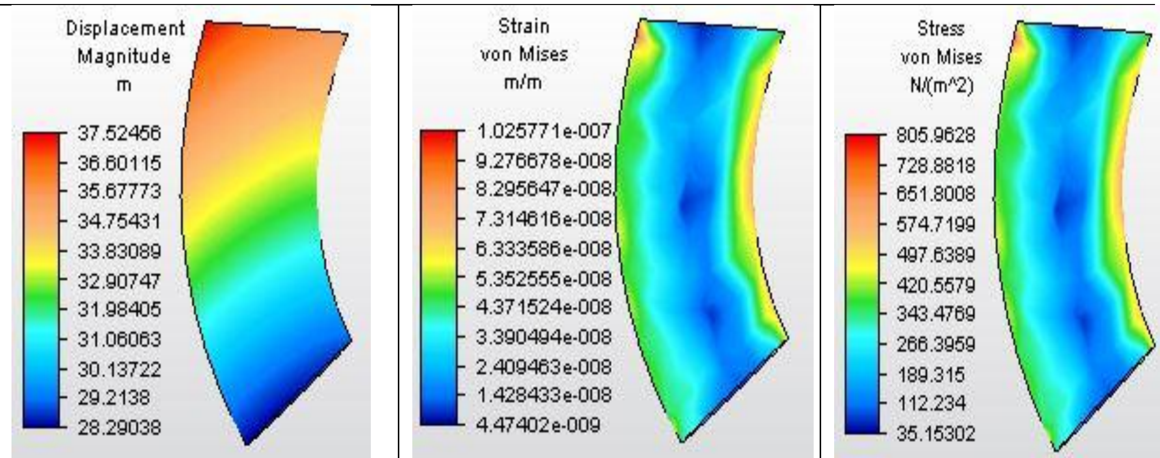
Force distribution 474.5570N







Force distribution 767.8874N



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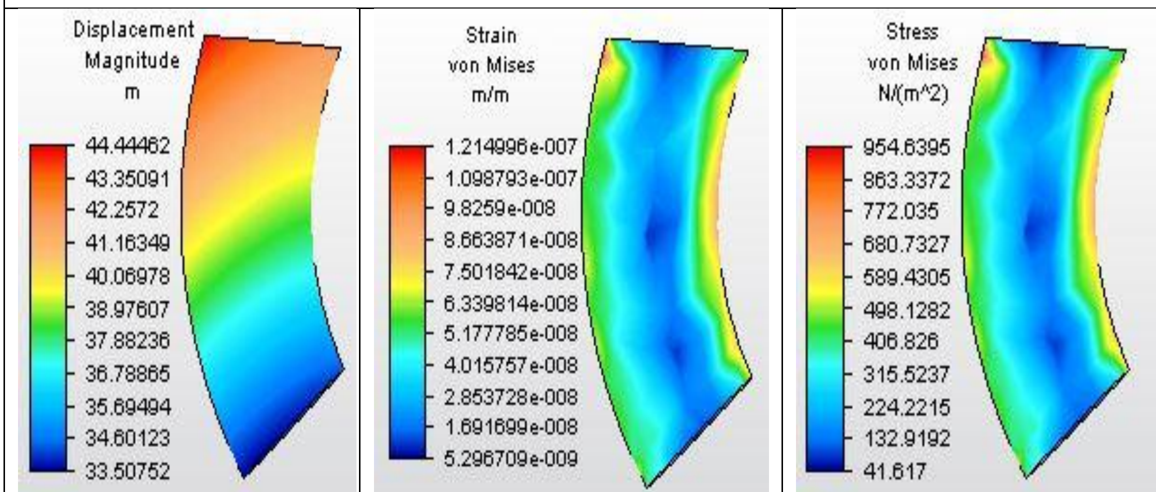

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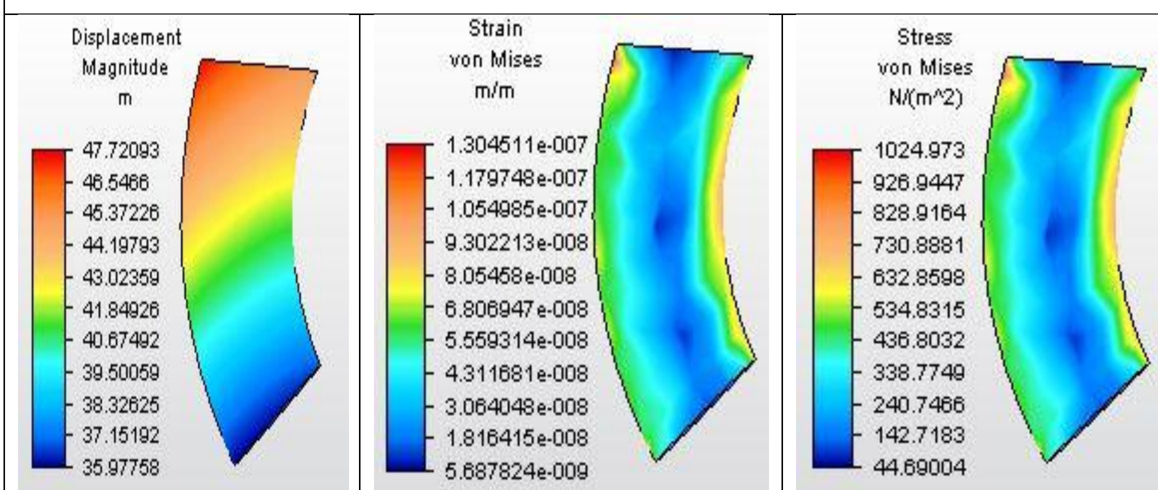
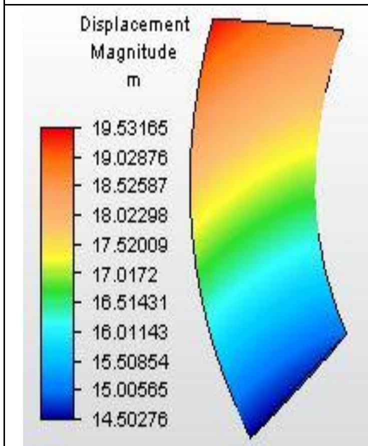
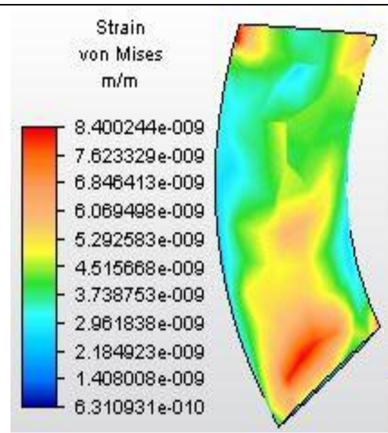
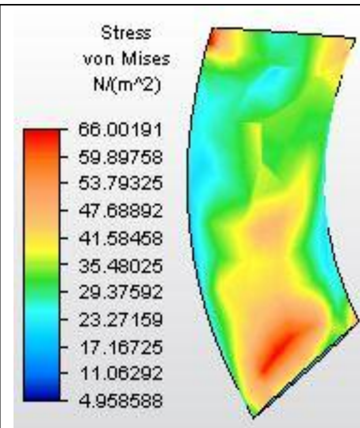


0degree of flexion for Palm Oil kneepad

Force distribution 474.5570N







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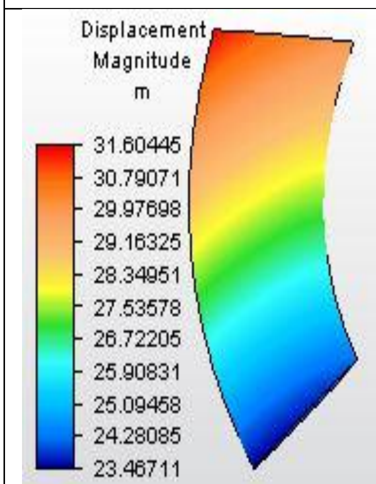

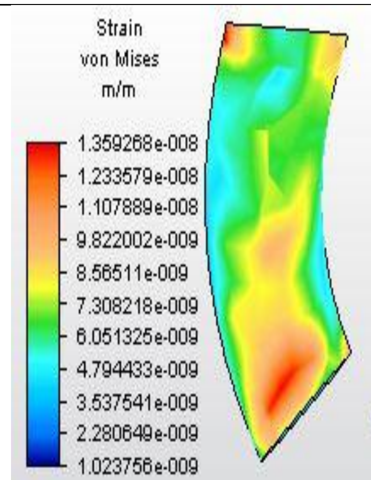

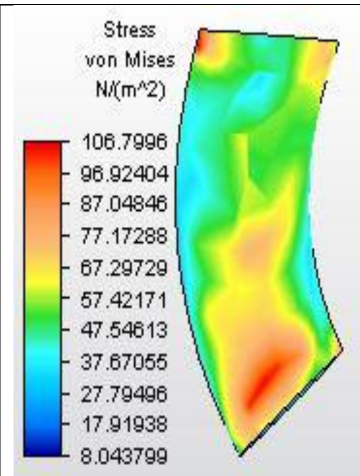

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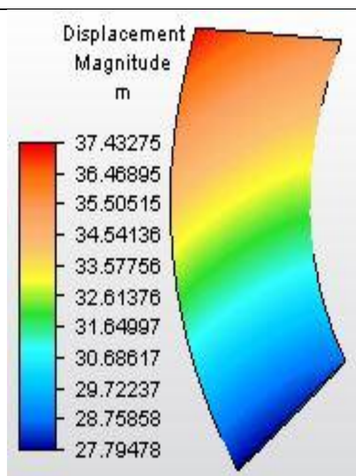
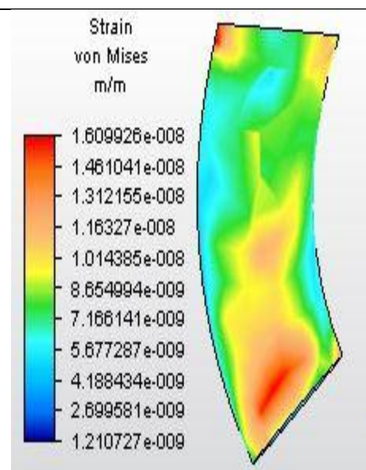
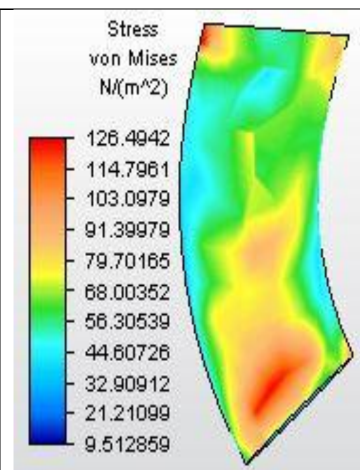
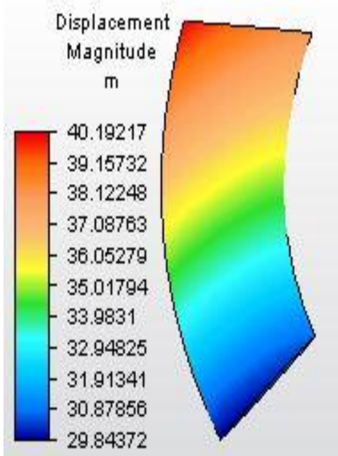
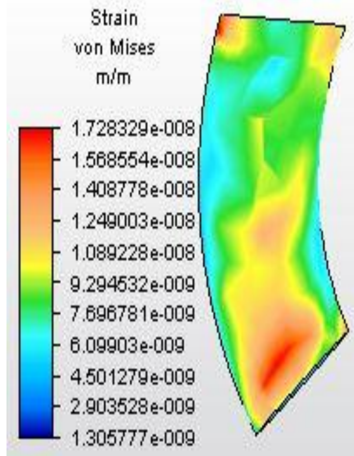


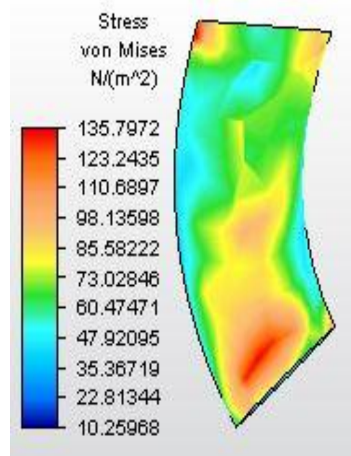




Force distribution 976.5417N

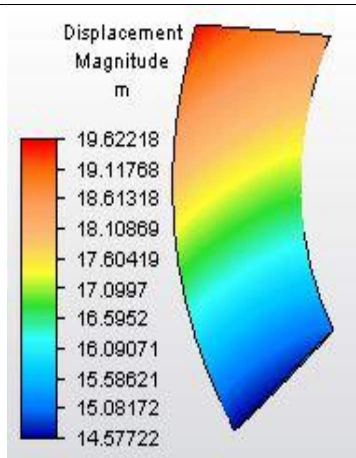


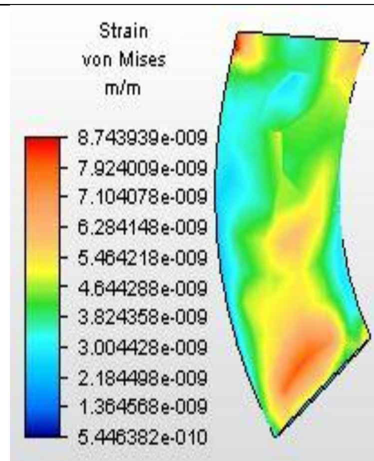


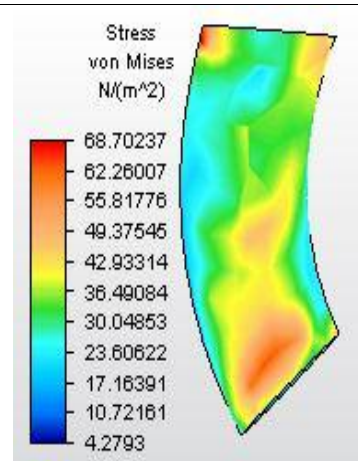


0degree of flexion for Saw Dusk kneepad

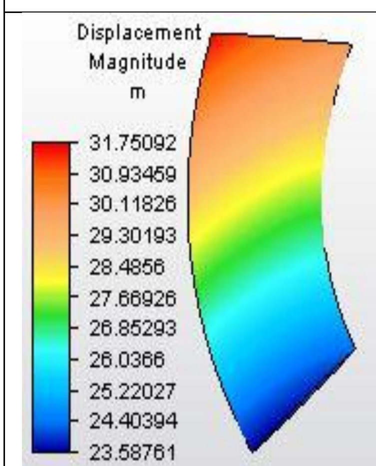
Force distribution 474.5570N

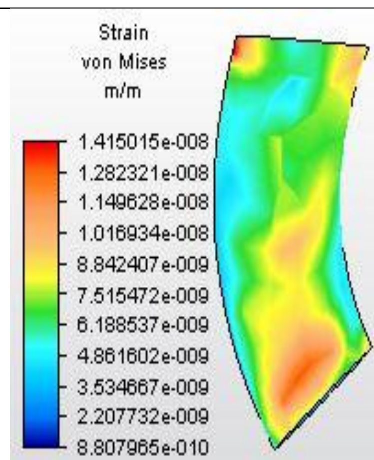


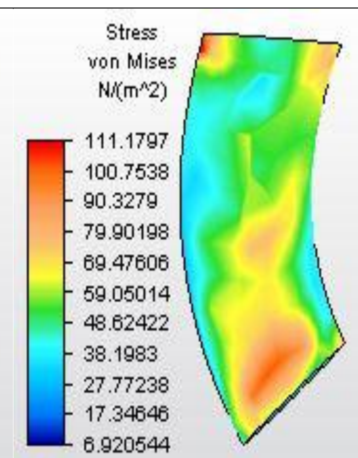




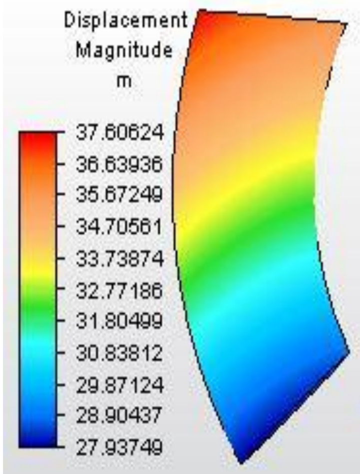
Force distribution 767.8874N

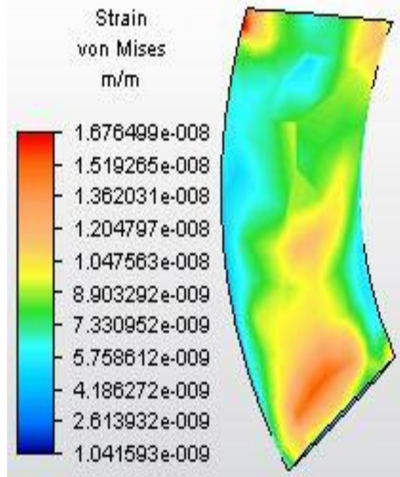


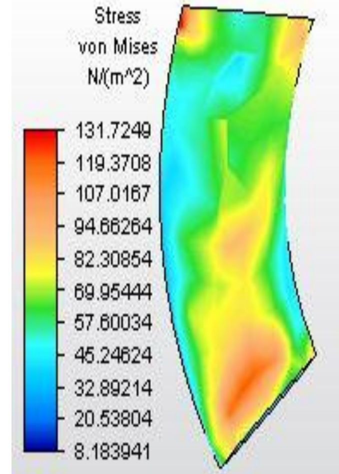




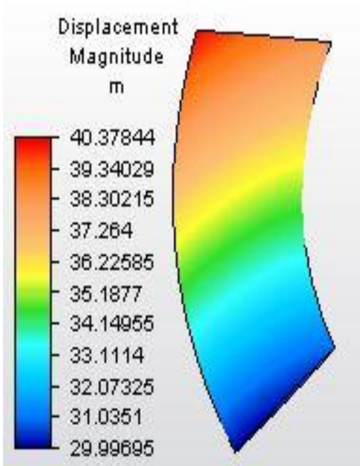
Force distribution 909.4966N

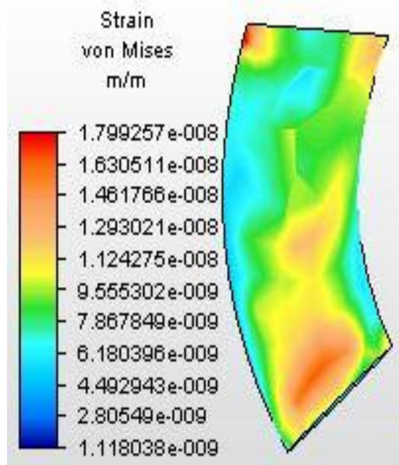


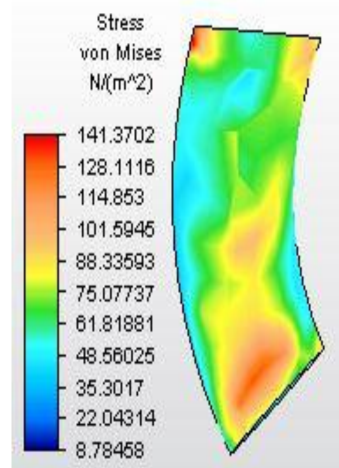




Force distribution 976.5417N

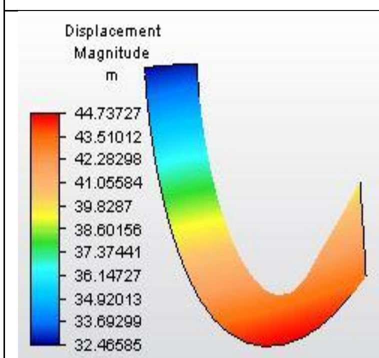


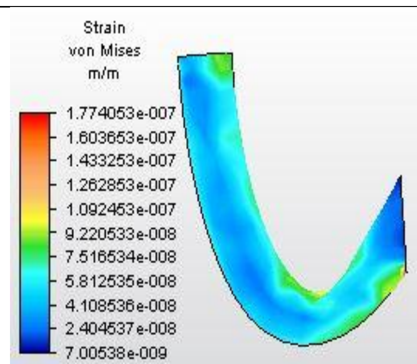


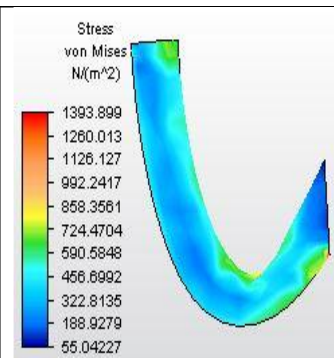


90degree of flexion for kenaf kneepad

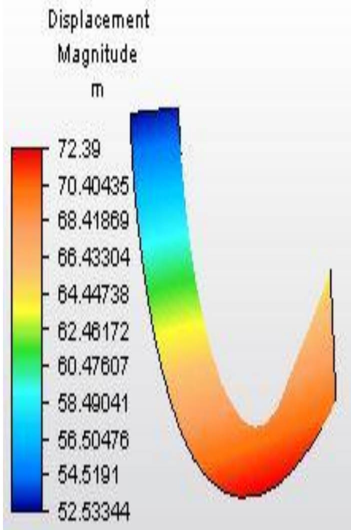
Force distribution 474.5570N

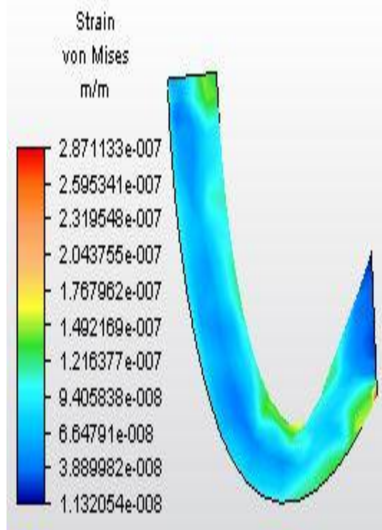


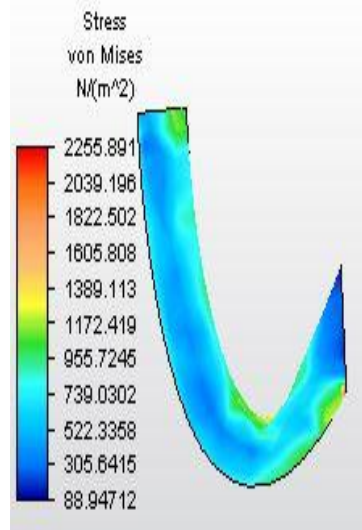




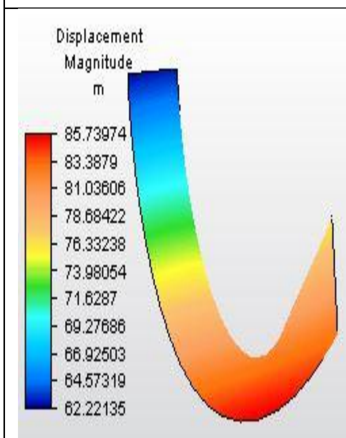
Force distribution 767.8874N

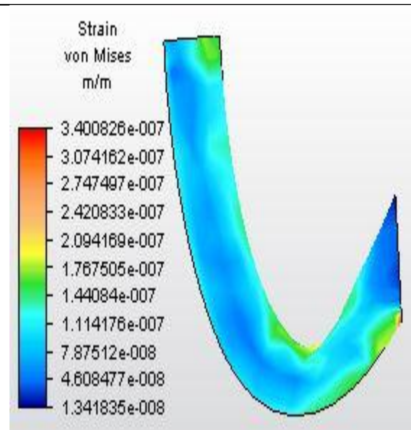


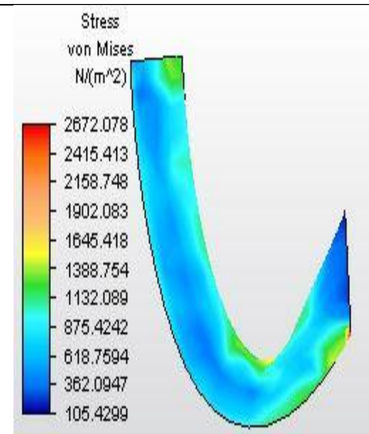




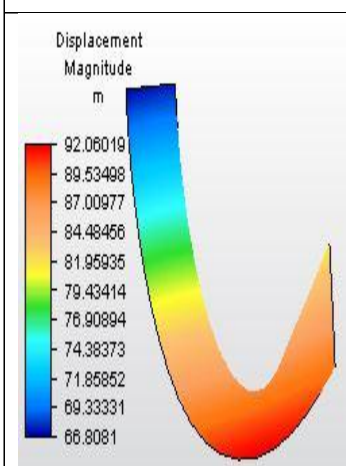
Force distribution 909.4966N

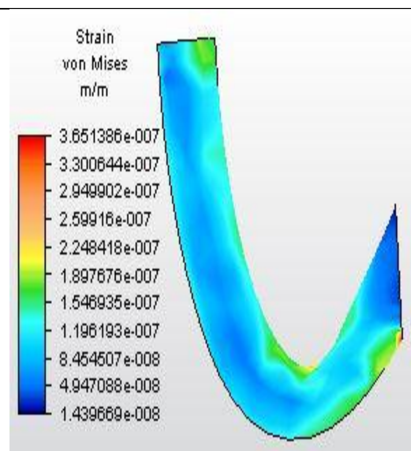


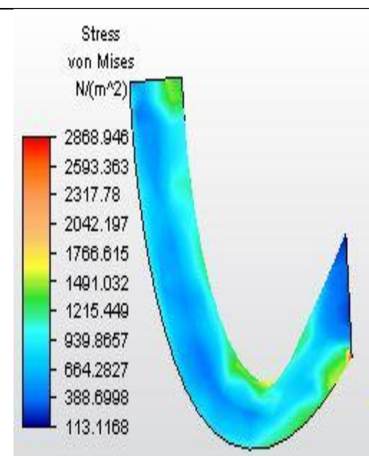




Force distribution 976.5417N

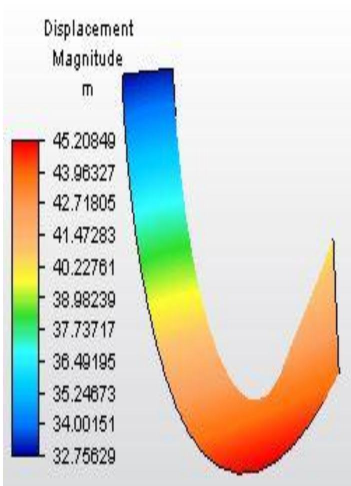


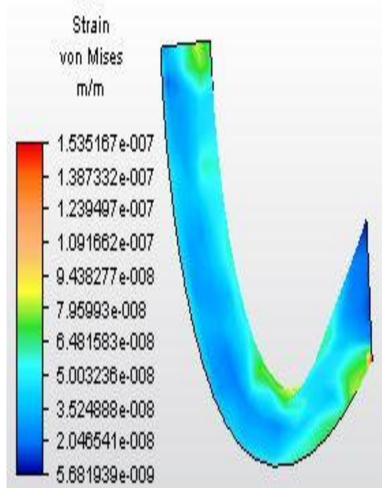


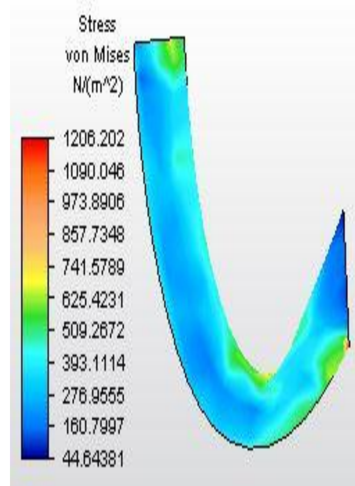


90degree of flexion for Coconut kneepad

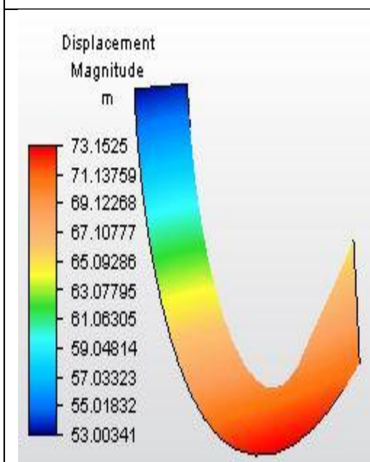
Force distribution 474.5570N

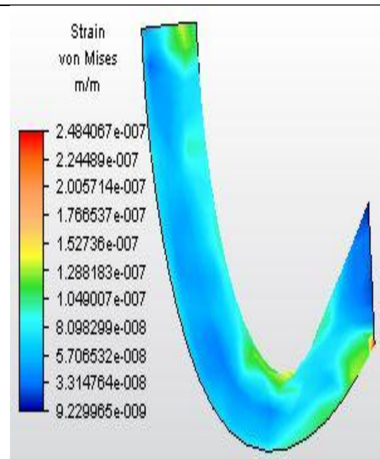


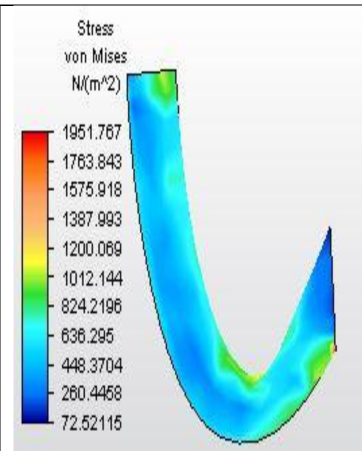




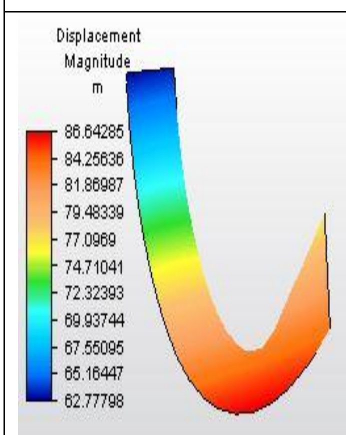
Force distribution 767.8874N

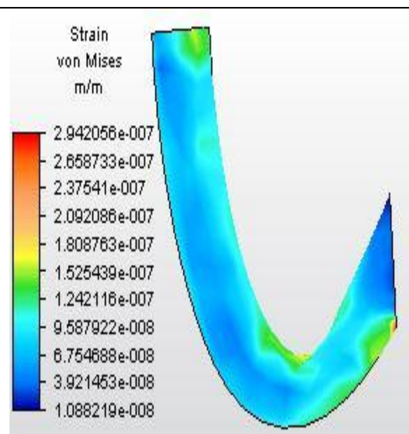


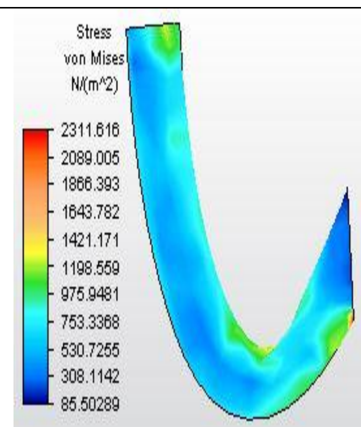




Force distribution 909.4966N







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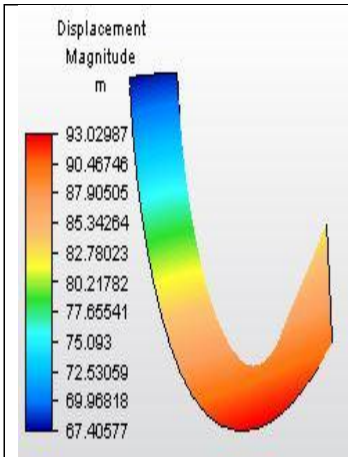
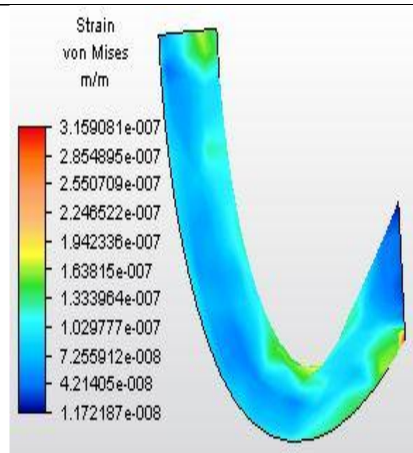
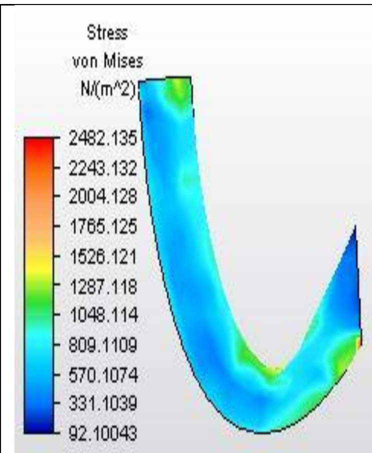
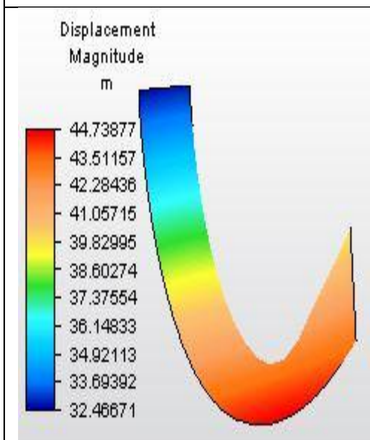


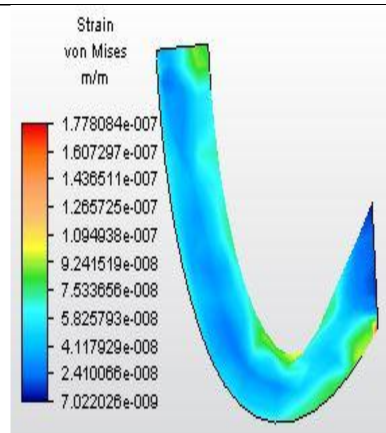


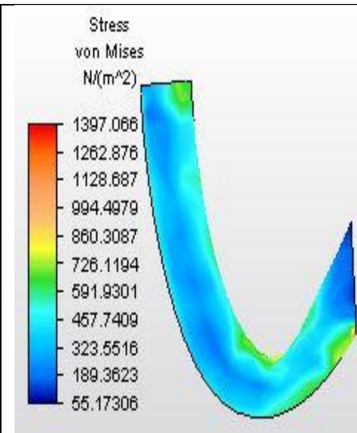


90degree of flexion for Palm Oil kneepad

Force distribution 474.5570N







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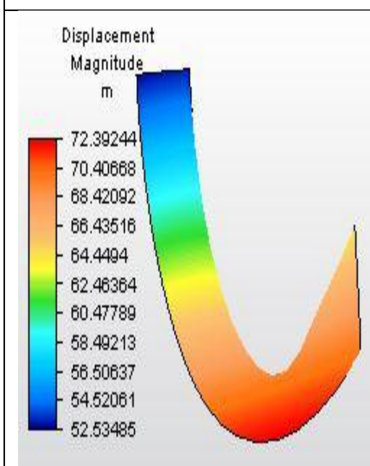

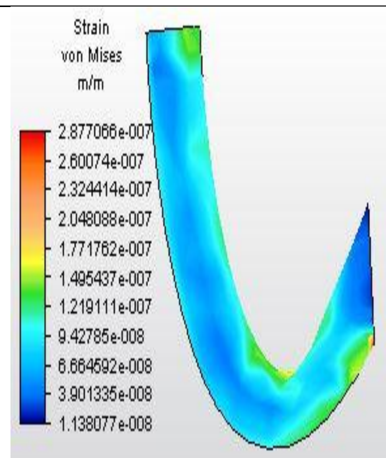

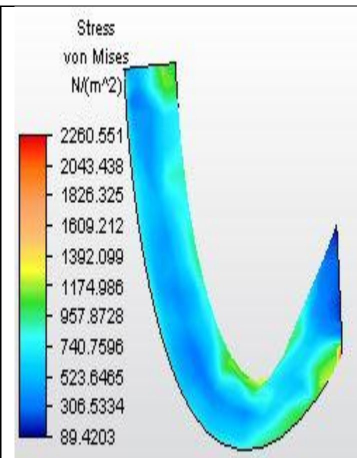

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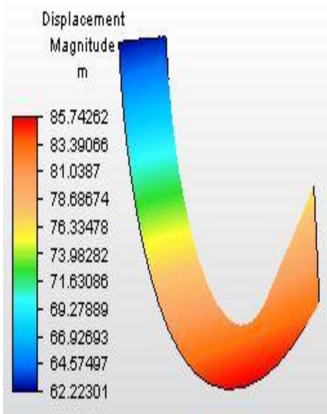

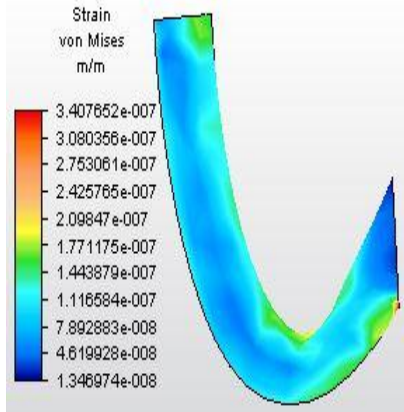

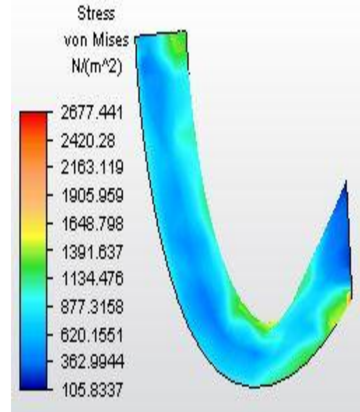

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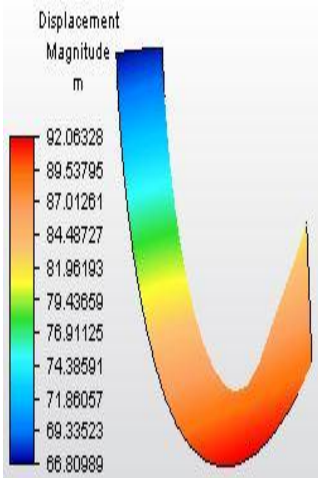
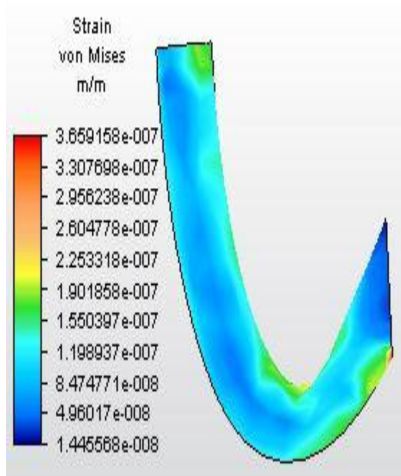
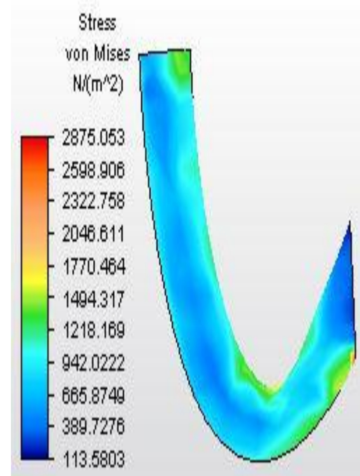
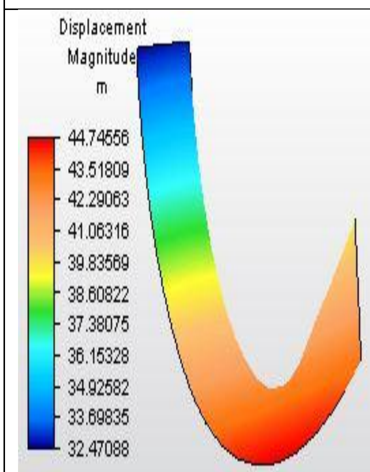


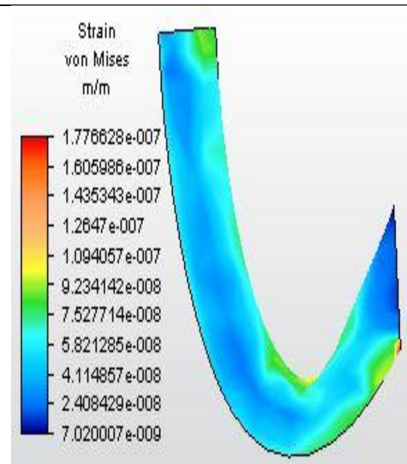


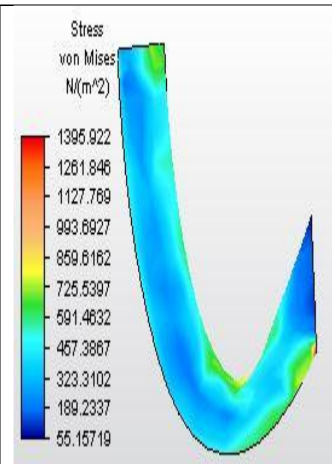


90degree of flexion for Saw Dusk kneepad

Force distribution 474.5570N







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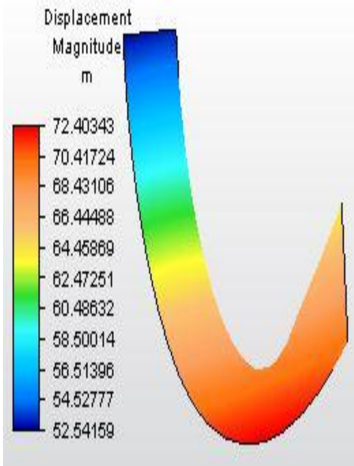

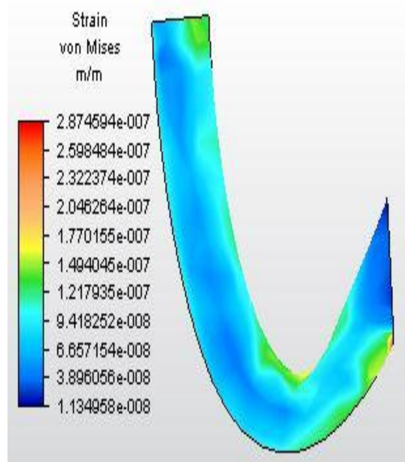

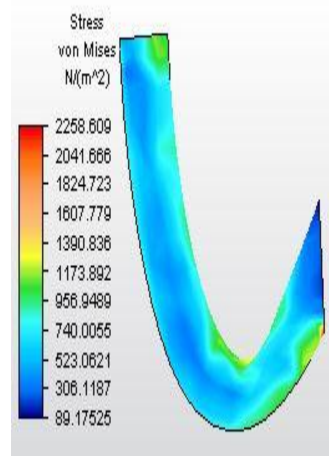

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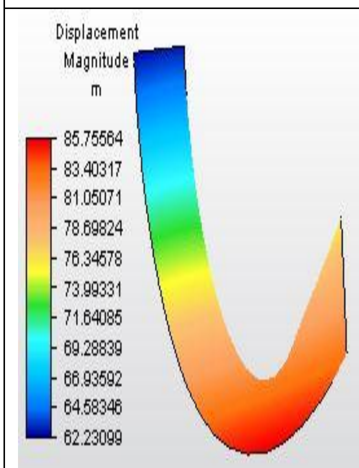

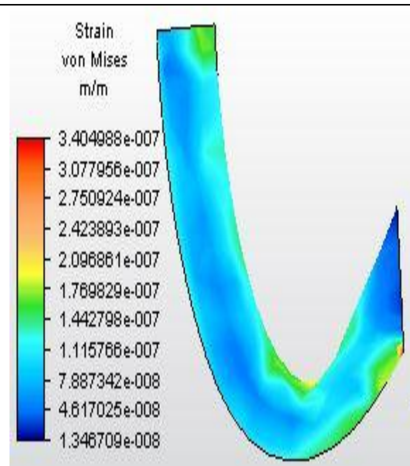

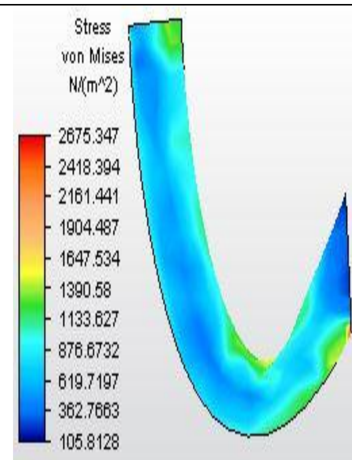

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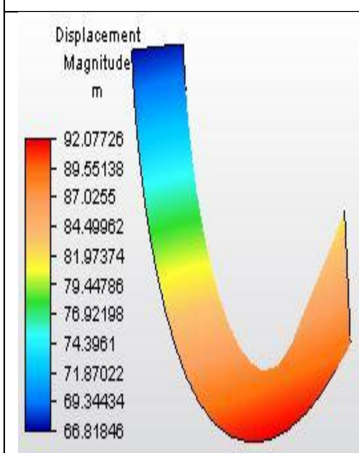

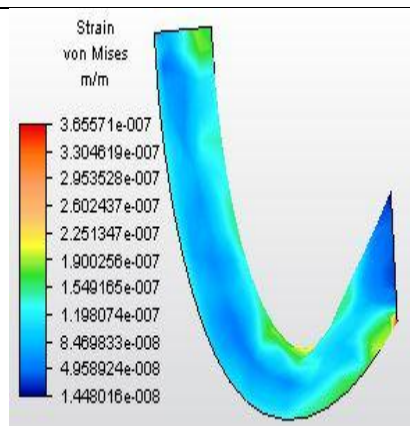

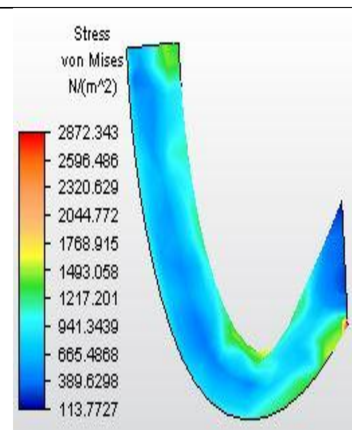

155degree of flexion for kenaf kneepad

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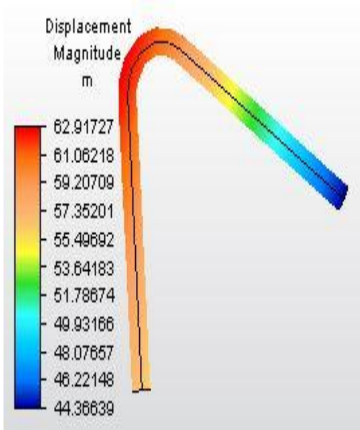
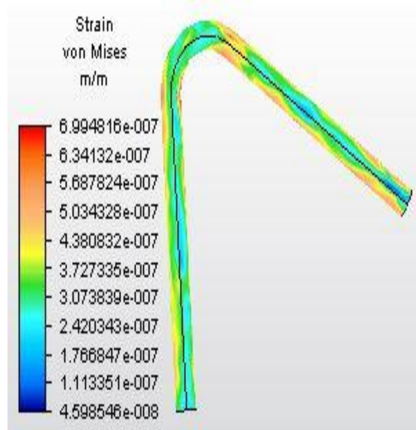
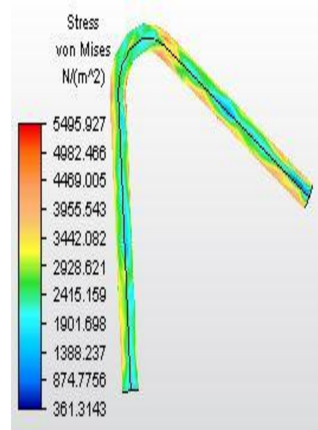
<td></td>
<td></td>
<td></td>
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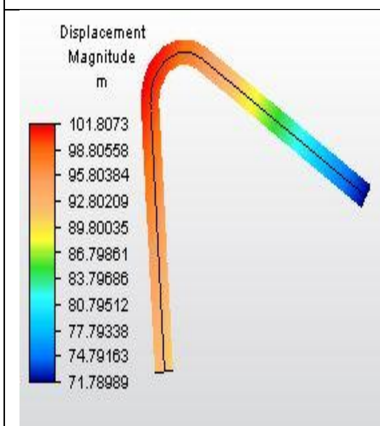
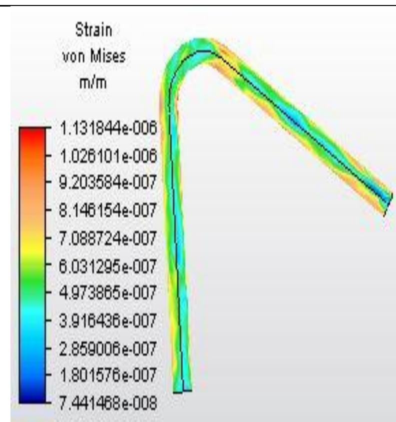
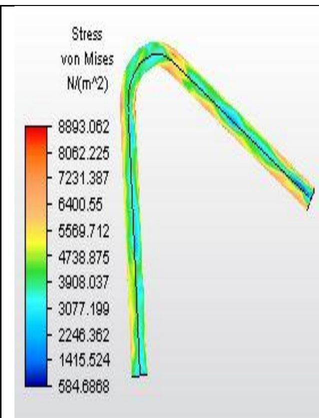
<td></td>
<td></td>
<td></td>
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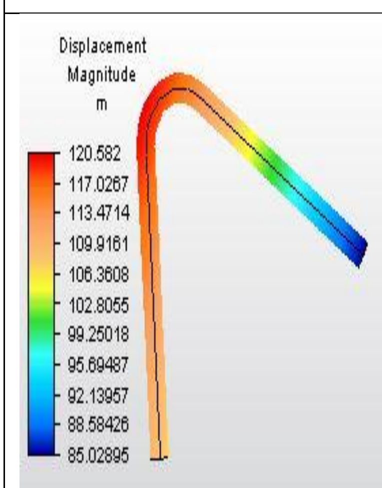
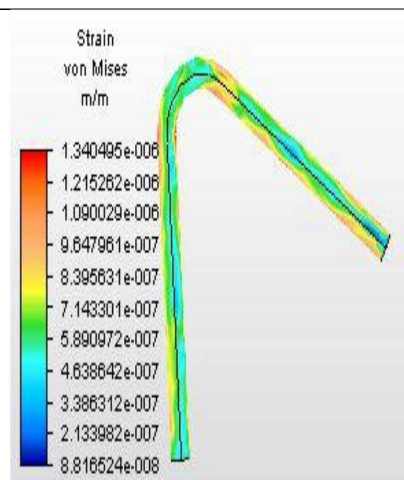
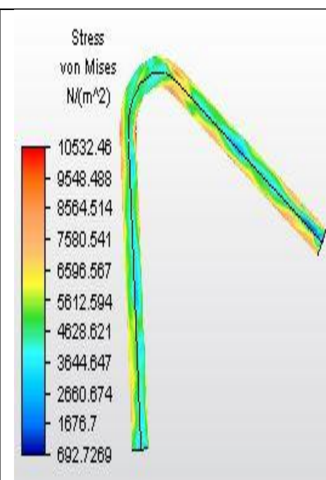
<td></td>
<td></td>
<td></td>
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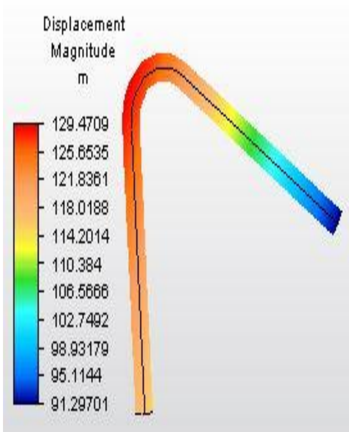	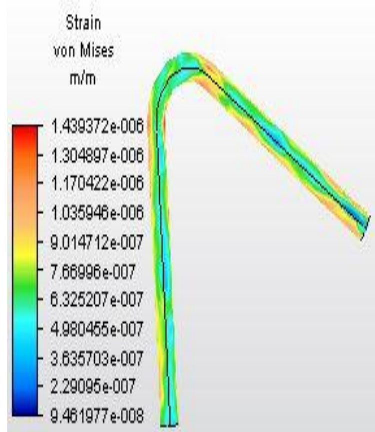	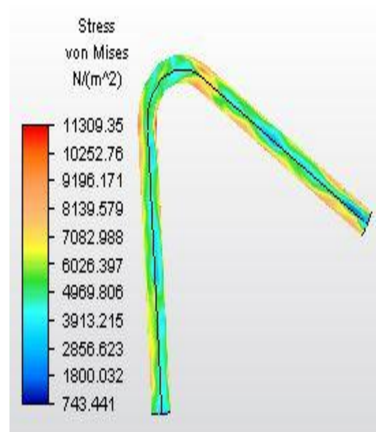
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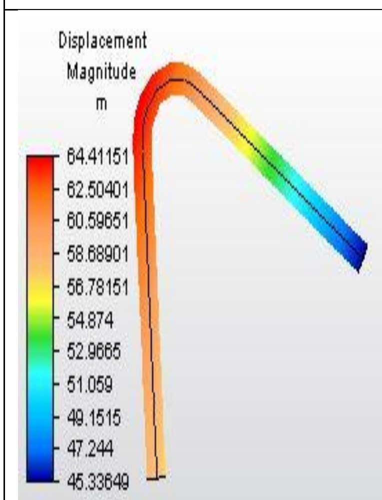	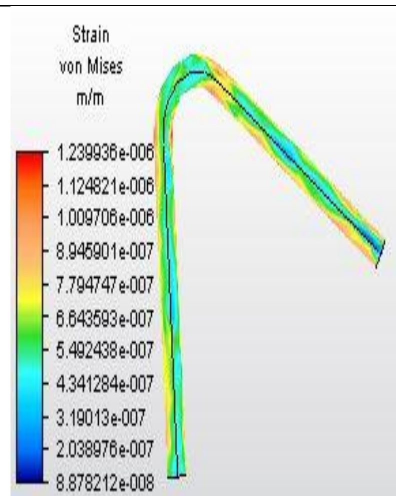	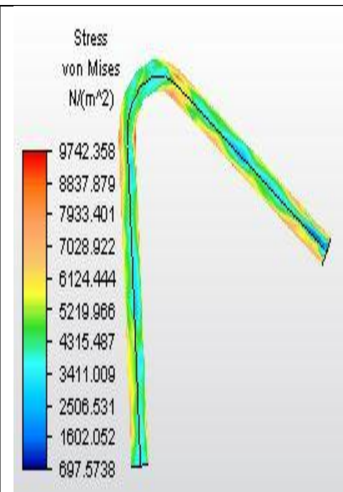
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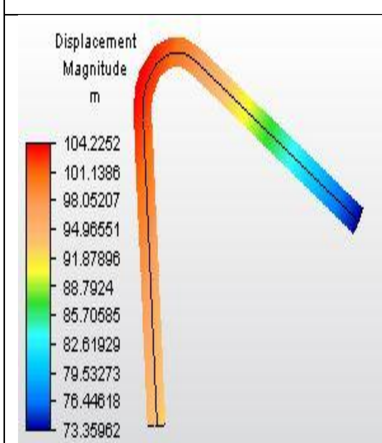	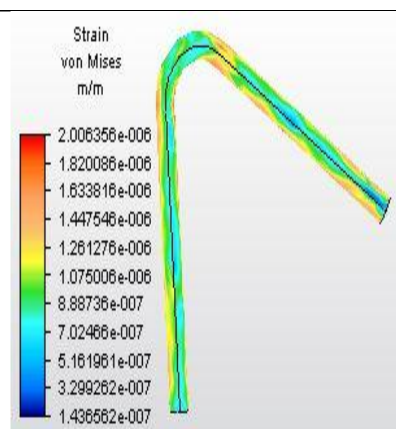	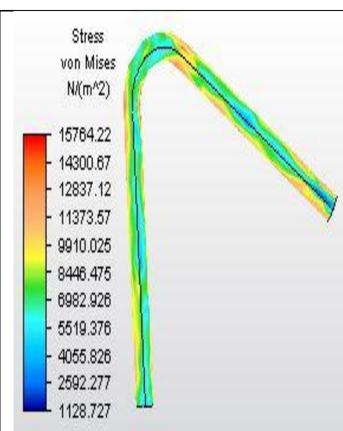

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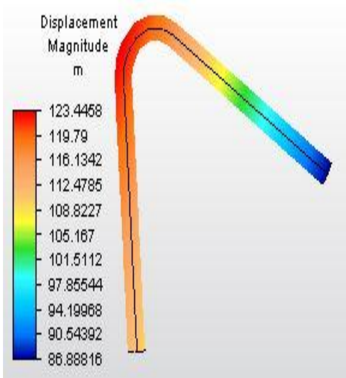

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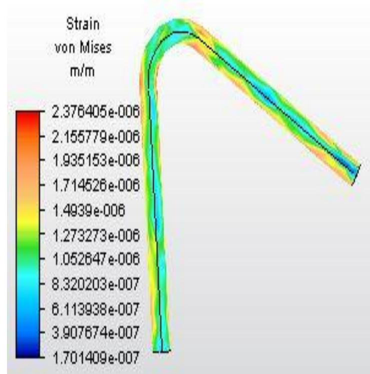

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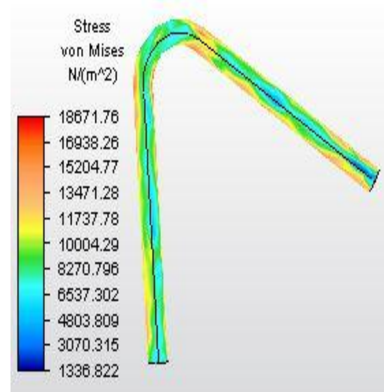

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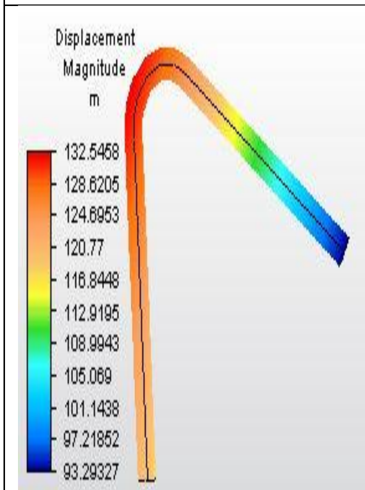

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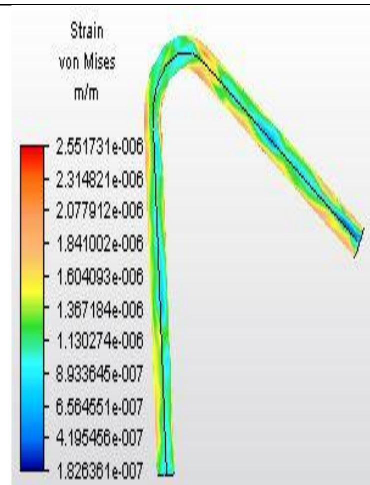

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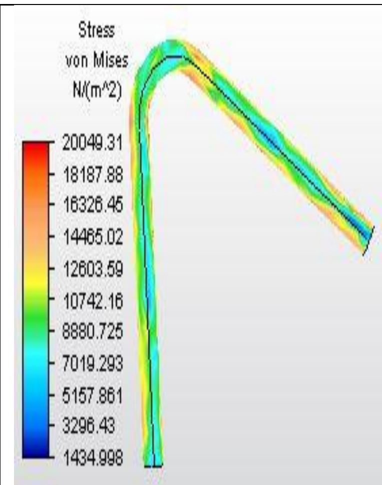

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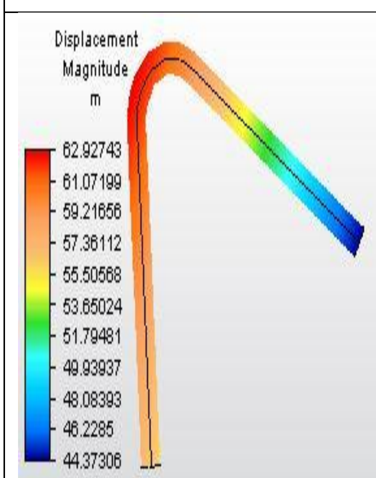

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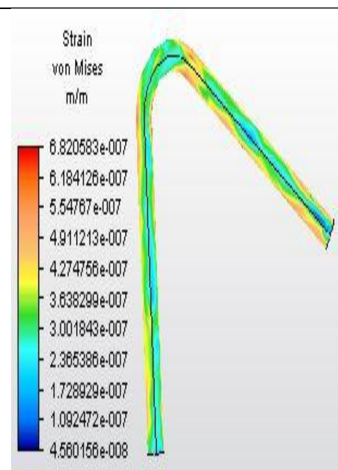

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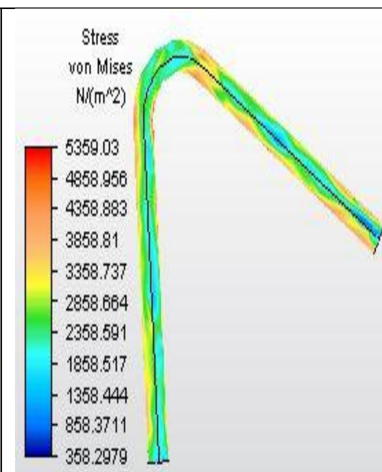

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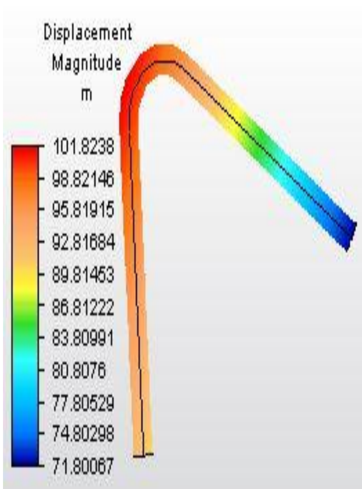
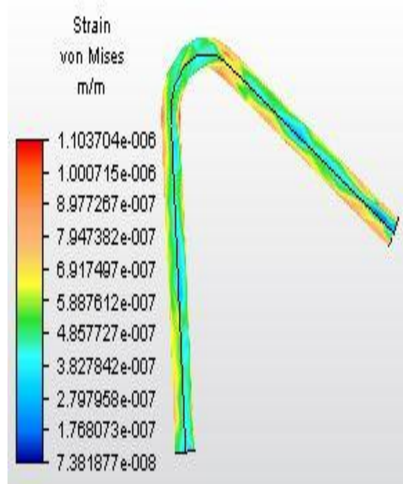
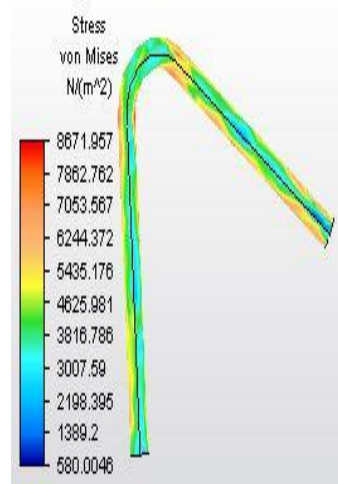
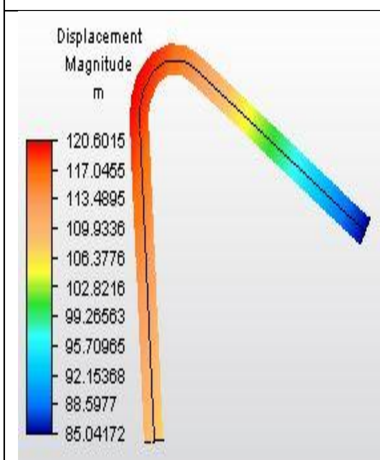
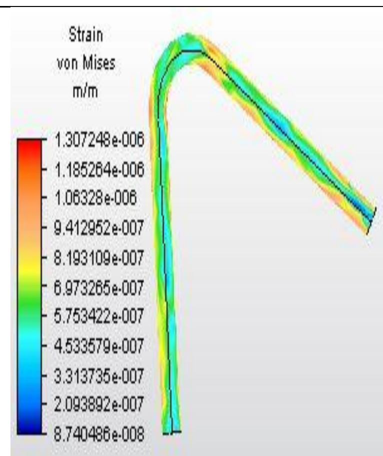


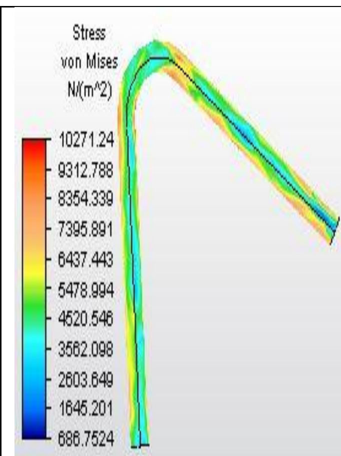




Force distribution 909.4966N







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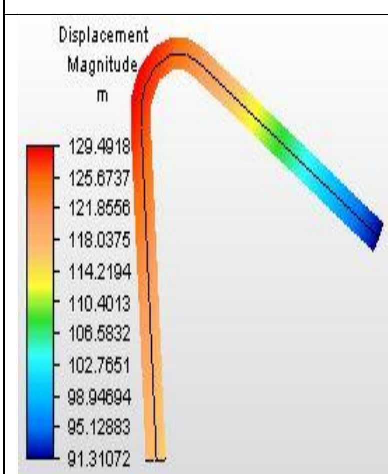
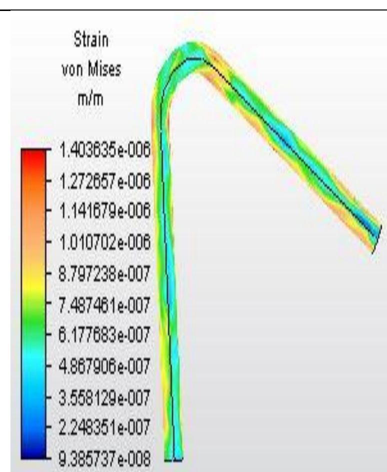
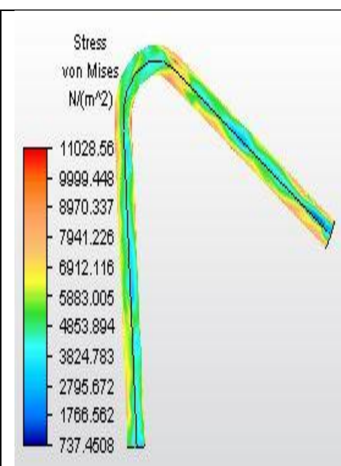
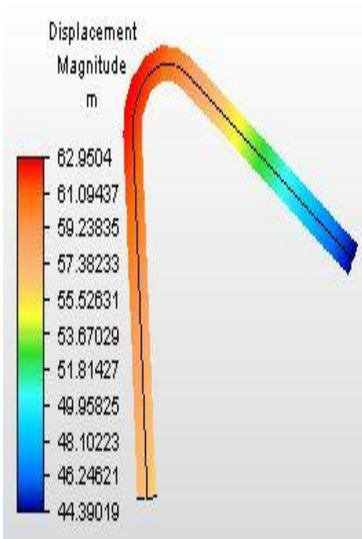


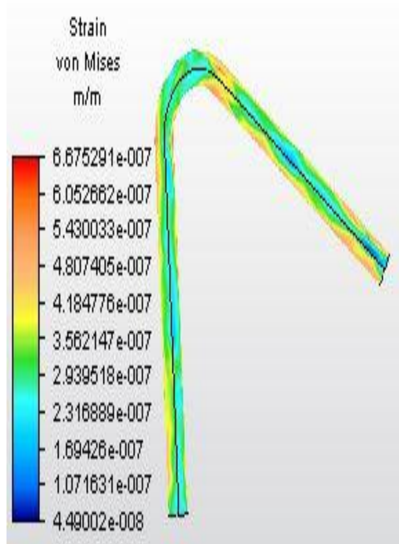


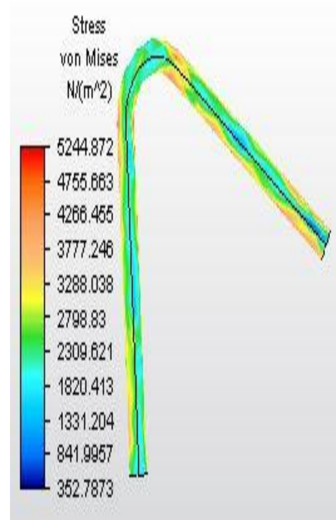


155degree of flexion for Saw Dusk kneepad

Force distribution 474.5570N







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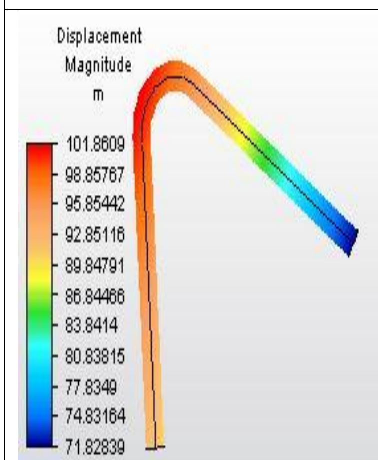

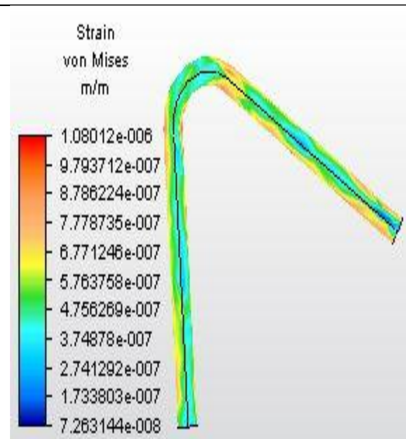

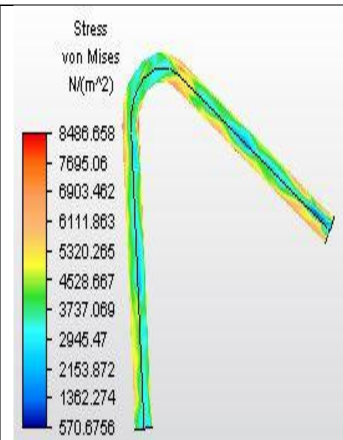

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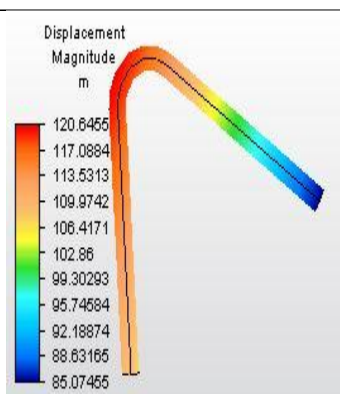

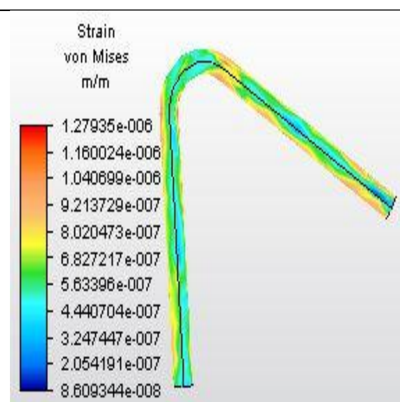

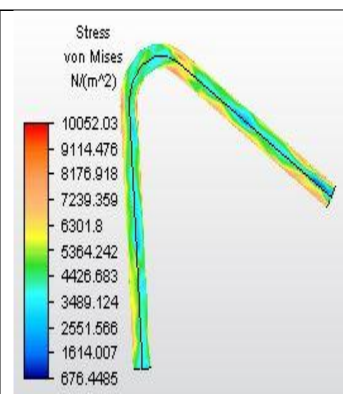

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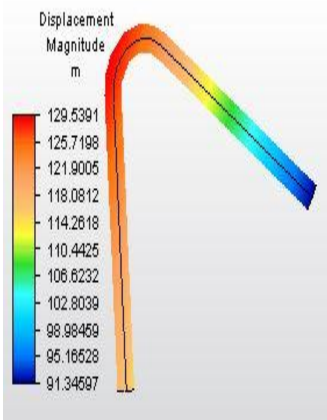

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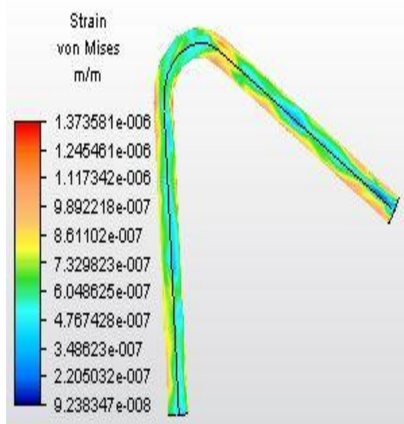

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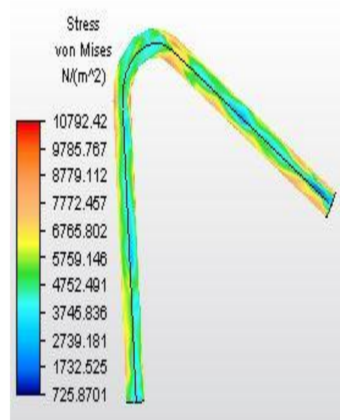

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