DESIGN AND ANALYSIS OF KNEE CAP

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ABSTRACT Knee replacement, also known as knee arthroplasty, is a surgical procedure to replace the weight-bearing surfaces of the knee joint to relieve pain and disability. It is most commonly performed for osteoarthritis and also for other knee diseases such as rheumatoid arthritis and psoriatic arthritis. In patients with severe deformity from advanced rheumatoid arthritis, trauma, or long-standing osteoarthritis, the surgery may be more complicated and carry higher risk. Osteoporosis does not typically cause knee pain, deformity, or inflammation and is not a reason to perform knee replacement. Other major causes of debilitating pain include meniscus tears, cartilage defects, and ligament tears. Debilitating pain from osteoarthritis is much more common in the elderly. Knee replacement surgery can be performed as a partial or a total knee replacement. In general, the surgery consists of replacing the diseased or damaged joint surfaces of the knee with metal and plastic components shaped to allow continued motion of the knee. The operation typically involves substantial postoperative pain and includes vigorous physical rehabilitation. The recovery period maybe 12 weeks or longer and may involve the use of mobility aids (e.g. walking frames, canes, crutches) to enable the patient's return to preoperative mobility. It is estimated that approximately 82% of total knee replacements will last 25 years.

KEYWORDS: Knee joint, Titanium, Biocompatibility, ANSYS, Solidworks

Introduction

A joint or articulation is the connection made between bones in the body which link the skeletal system into a functional whole. They are constructed to allow for different degrees and types of movement. Some joints, such as the knee, elbow, and shoulder, are self-lubricating, almost frictionless, and can withstand compression and maintain heavy loads while still executing smooth and precise movements. Biomechanical classification of Joints can also be classified based on their anatomy or their biomechanical properties. The main aim is to work on the complex joint, which has two or more articular meniscus like a knee joint. In most of the human joints knee, the joint is the stressed part due to the whole weight of the body is subjected on it. Nowadays, many people are suffering from knee joint pains, and they need an efficient solution to this problem. The best possible solution for this problem is knee replacement.

Knee replacement, also known as knee arthroplasty, is a surgical procedure to replace the weight-bearing surfaces of the knee joint to relieve pain and disability. It is most commonly performed for osteoarthritis, and also for other knee diseases such as rheumatoid arthritis and psoriatic arthritis. In patients with severe deformity from advanced rheumatoid arthritis, trauma, or long-standing osteoarthritis, the surgery may be more complicated and carry higher risk. Osteoporosis does not typically cause knee pain, deformity, or inflammation and is not a reason to perform knee replacement. Other major causes of debilitating pain include meniscus tears, cartilage defects, and ligament tears. Debilitating pain from osteoarthritis is much more common in the elderly. Knee replacement surgery can be performed as a partial or a total knee replacement. In general, the surgery consists of replacing the diseased or damaged joint surfaces of the knee with metal and plastic components shaped to allow continued motion of the knee. Knee replacement surgery is most commonly performed in people with advanced osteoarthritis and should be considered when conservative treatments have been exhausted. Total knee replacement is also an option to

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correct significant knee joint or bone trauma in young patients.

Similarly, total knee replacement can be performed to correct mild valgus or varus deformity. Valgus severe or varus deformity should be corrected by osteotomy. Physical therapy has been shown to improve function and may delay or prevent the need for knee replacement. Pain is often noted when performing physical activities requiring a wide range of motion in the knee joint. Knee joints are damaged due to injuries, mechanical problems types of arthritis and other problems. A knee injury can affect any of the ligaments, tendons or fluid-filled sacs (bursae) that surround your knee joint as well as the bones, cartilage and ligaments that form the joint itself. Some of the more common knee injuries include:

ACL injury, Fractures, Torn meniscus, Knee bursitis and, Patellar tendinitis. The mechanical problems that can cause knee pain include Loose body, Iliotibial band syndrome, Dislocated kneecap and, Hip or foot pain. The teaching and learning is the most critical activity in the education system the study to find out which among them is best was the aim of the research. The research can be extended by using other sectors in education filed for Primary education and other professional education courses. The study was conducted for one particular city. It can extend to other cities [1]. The first part of this study is based on the hypothesis that the patterns of contact stress on the tibial insert of a knee prosthesis. The second part of this study addresses the long-term structural integrity of metal tibial components in terms of fatigue life. Experimental and computational results showed a positive matching.

In conclusion, both computational and experimental methods play an essential role in designing reliable prostheses [2]. In this study, a computational model was developed to predict the micro-mechanical stimuli, such as stress and strain, fluid pressure and flow, of cells and their surrounding PCM in the AF tissue using three dimensional (3D) finite element models based on in situ morphology. These studies provide Spatio-temporal information on micromechanics of AF cells in understanding the mechanotransduction in the intervertebral disc [3].

The defects on the high-cycle fatigue behaviour of laser-welded Ti-6Al-4V butt joints. The transition of the crack origin from the surface to the subsurface occurs upon removal of the surface stress concentrators. Using statistical methods, the experimentally determined porosity distribution has been incorporated into the model to predict the fatigue scatter range. The presented methodology can potentially be used to achieve the required reliability of the welded joints concerning fatigue as a design criterion [4]. The properties of commercial pure titanium (CP-Ti) grade 4 by comparing spark plasma sintering (SPS), cold isostatic press (CIP). Pre-compacted bodies were isothermally held for 10 minutes at 1250°C under the pressure of 10MPa in SPS method, while the CIP and sinter method involved the isothermal holding of pre-compacted bodies for 1 hour at 1350°C in the tube furnace under argon gas atmosphere. The SPS and casting methods resulted in highly dense materials. The microstructural features were homogeneous and mainly consisted of plate-like α-Ti phase for all three technologies [5]—the lubrication for machining of Ti-6Al-4V.

Vegetable oils have often been proposed as sustainable alternatives to the conventional synthetic emulsion coolants. The current study investigates the effect of six different strategies on the flank tool wear, surface roughness and energy consumption during turning of titanium Ti-6Al-4V using uncoated carbide tool at a certain speed and feed. The use of rapeseed vegetable oil in MQL and MQCL configuration turns out to be an overall sustainable alternative. Thus confirming the promise predicted in the use of vegetable oil as a lubricant for machining [6]. Titanium (Ti-6Al-4V) alloy is mainly utilized in fabricating medical device applications. Since it has high strength, it is very difficult to machine alloy using conventional machining. AWJM process is used for machining titanium.

Since the process involves less heat affect zone and higher material removal, it is possible to enhance the machinability of the workpiece. It has attempted to find the influence of process parameters on surface roughness and topography for enhancing the process. It has been observed that the abrasive flow rate and standoff distance has the most significant role in determining surface quality [7]. Titanium alloy (Ti-6Al-4V) Grade 5 is the most popular alloy widely used in Biomedical part manufacturing due to its inherent properties. However, on the other hand, Ti-6Al-4V shows machining challenges on-base performance criteria like metallurgical aspect, chip formation, cutting tool wear, lubrication strategy and surface integrity. In this paper study of various machining problem discussed by different researchers and their probable solution, which helps to reduce tool wear, high surface finish with effective lubrication strategy by reducing machining complexity. Surface finish is directly depending upon machining conditions. The good surface finish obtained at a minimum depth of cut, maximum R.P.M., with the low cutting speed in wet machining. Dry machining should be avoided for saving tool life and surface texture [8].

The microstructure, hardness, tensile deformation and final fracture behaviour of an emerging titanium alloy for performance-critical applications are presented and discussed. Both longitudinal and transverse test specimens were prepared from the as-provided sheet stock of the alloy and deformed in uniaxial tension. The yield strength and tensile strength of the alloy sheet in the transverse orientation was higher than the longitudinal orientation. The ductility of the test specimens, quantified in terms of reduction-in-cross-sectional area, was higher for the transverse specimen when compared to the longitudinal counterpart. The tensile fracture behaviour of the alloy was quantified by careful examination of the fracture surfaces in a scanning electron microscope. The intrinsic fracture features on the tensile fracture surface were discussed, taking into consideration the nature of loading and contribution from intrinsic microstructural features [9]. The Young's modulus (E), Poisson's ratio (v) and anisotropy parameter (AG) of α' phase, which obtained from different solution treatment and water quenching temperature, were investigated using first-principles calculations based on density functional theory (DFT). The calculation results showed that the value of the elastic modulus of α' phase was higher than that of the elastic modulus of α' phase was anisotropic.

In order to verify the calculation results, the elastic modulus anisotropy of macroscopic Ti-6Al-4V alloys, which were treated at 850ºC, 900ºC and 950ºC, were tested by the tensile and the compressive experiments. The experimental results showed the same change tendency with the calculation results [10]. Tungsten Inert Gas welded titanium sheet of 1.5 mm thickness is considered as a candidate material for investigation. The weld joint is prepared using 80 A welding current and 200 mm/min travel speed. Tensile properties are evaluated at room temperature, 250 °C, 450 °C and 650 °C. The ultimate strength and yield strength decreases with increase in temperature and also the percentage elongation increases with increase in temperature.

At temperatures above 650°C, the ultimate tensile strength (UTS) had decreased to about 66% than the ultimate tensile strength (UTS) at room temperature [11]. The results of a study of phase composition and microstructure of initial material and samples obtained by selective laser melting of titanium-based alloy, as well as samples after heat treatment. The effect of heat treatment on microstructure and mechanical properties of specimens was shown. The heat treatment allows obtaining sufficient mechanical properties of the material at room and elevated temperatures such as an increase in ductility of the material. The microstructure of the bulk specimens after SLM is martensitic α'-phase in the form of fine-dispersed acicular precipitates. The fractography of samples showed that they feature ductile fracture with brittle elements [12].

The characterization study of specimens manufactured from Ti-6Al-4V powder with the use of laser engineered net shaping technology (LENS). Two different orientations of the specimens were considered to analyse the loading direction influence on the material mechanical properties. Moreover, two sets of specimens, as-built (without heat treatment) and after heat treatment, were used. Microstructure characterization was examined with the use of optical and scanning electron microscopes (SEM); besides, the electron backscatter diffraction (EBSD) was also used. The fracture mechanism was discussed based on the fractography analysis. The material data was used to obtain parameters for the selected constitutive model to simulate the energy-absorbing structures manufactured with LENS technology. The numerical modelling confirmed the correctness of the acquired material data resulting in a reasonable reproduction of the material behaviour during the cellular structure deformation process [13]. A comparative investigation of mechanical properties of Ti–6Al–4V titanium alloy with microcrystalline and sub-microcrystalline structures in the temperature range of 20–600°C has been carried out.

The grain sizes under the sub-microcrystalline and microcrystalline conditions are 0.4 and 10mm, respectively. The structure refinement of the alloy results in an increase in both strength and fatigue limit at room temperature by about 20%. With increasing deformation temperature, the strength of the sub-microcrystalline alloy is higher than that of the microcrystalline alloy up to 400°C. The creep strength of the sub-microcrystalline alloy is slightly lower than that of the heat-strengthened microcrystalline alloy already at 250°C [14]. Titanium Alloy (Ti-6Al-4V) is the most widely used because it features good machinability and excellent mechanical properties when compared to the Pure Titanium. These alloys are widely used in the biomedical parts, because of their high specific strength and exceptional corrosion resistance. However, the machinability of titanium alloys is difficult due to their low thermal conductivity and elastic modulus, high hardness at elevated temperature, and high chemical reactivity. In this article to overcome this disadvantage of machinability, the material is heat-treated, which increases the machinability. The effect of heat treatment on the mechanical properties of the titanium alloy is compared by the results obtained in the Universal Testing Machine (UTM), Hardness Testing, Scanning Electron Microscope (SEM) for the both the Non-Heat Treated Specimen and Heat Treated Specimen [15]. Ti-6Al-4V and stainless steel 316L have been processed by selective laser melting under similar conditions, and their microstructures and mechanical behaviours have been compared in details. Under the investigated conditions, Ti-6Al-4V exhibits a more complex behaviour than stainless steel 316L with respect to the occurrence of microstructural and mechanical anisotropy. Moreover, Ti-6Al-4V appears more sensitive to the build-up of internal stresses when compared with stainless steel 316L, whereas stainless steel 316L appears more prone to the formation of "lack of melting" defects [16].

The machining parameters. Titanium alloy machining is hindered basically due to its high chemical reactivity and low thermal conductivity. The cutting speed, feed and depth of cut were used as the process parameters whereas the cutting force and temperature were selected as performance characteristics. The degree of influence of each process parameter on individual performance characteristic was analysed from the experimental results obtained using the Taguchi Method. The cutting speed was identified as the most influential process parameter on cutting force and temperature [17]. The purpose of this study was to evaluate the effect of heat treatments on the Vickers hardness of commercially pure titanium and Ti6Al-4V cast alloys. Commercially pure titanium and Ti-6Al-4V alloy specimens were randomly assigned to 3 groups (n=10) that received the following heat treatments. After heat treatments, the specimens were embedded in acrylic resin, and their surface was ground and polished, and hardness was measured. Vickers hardness means (VHN) and standard deviations were analyzed statistically by Kruskal-Wallis test at 5% significance level. The results demonstrated different hardness of CP Ti and Ti-6Al-4V when different heat treatments were used. For CP Ti, VHN means of T2 group was remarkably higher than those of control and T1 group, which showed similar VHN means to each other. For Ti-6Al-4V alloy, however, VHN means recorded for each group may be presented as follows: T2>T1>control [18].

Titanium alloys are known for their good mechanical properties, low density, excellent corrosion resistance and low thermal conductivity. Unfortunately, the thermal cycle during welding of alpha-beta alloys (Ti-6Al-4V) can significantly change their strength, toughness and plasticity. The scope of present work is to investigate the possibility for producing Ti-6Al-4V welds by arc discharge in a vacuum and to establish the influence of the welding parameters on dimensions and mechanical properties of the welds. The results, presented in this work, describe the dimensions of the fusion zone and heat-affected zone of welds, produced by hollow cathode arc welding using different welding parameters. The mechanical properties of the welds were determined [19].

The experimental investigation on the flow stress behaviour of Ti6Al-4V alloy at elevated temperatures and very low strain rate. Though Ti-6Al-4V alloy is very hard to deform at room temperature, having only about 16% elongation, it exhibits superplasticity at elevated temperatures. To investigate this, the tensile tests were conducted from 7000C to 9000C temperatures. The experimental study shows more than 50% elongation in all the cases and particularly more than 250% elongation at 0.0001 /s strain rate and at 7500C to 9000C temperature in all directions, which is an indication of super-plasticity in the material. This is also corroborated by the microstructural study of the fractured specimens [20]. The effects of machining parameters on surface roughness, Material removal rate and roundness error in wet turning of Ti-6Al-4V. Multi layered CVD coated carbide tool with different nose radius are chosen for this work. Combined effects of four cutting parameters, namely cutting speed, feed rate, depth of cu and nose radius on performance measures such as surface roughness, Material removal rate and roundness error, are explored by Grey relational analysis. These responses

are essential factors to evaluate cutting performance and also influences the product quality, product cost etc [21]. Cutting tool life, its wear rate and machining cost play a significant role in a machining process. Effect of these parameters using face milling of titanium alloy is analysed to assess the economic factor of sustainability. Experiments are designed in DOE for central composite design and performed face milling of Ti-6Al-4V with PVD coated carbide inserts using three conditions of cooling and measured the response values. Feed, speed, and depth of cut were used as input variables. The results indicate that cryogenic cooling is more sustainable for tool life, having a better surface finish of the machined part with the least energy and machining cost [22].

The investigation assessed the biomechanical performance of the metal plate and bone strut technique for fixing recalcitrant nonunions of femur midshaft segmental defects, which has not been systematically done before. A finite element (FE) model was developed and then validated by experiments. This study computationally and experimentally examined plate and strut fixation of a large femoral midshaft segmental defect. Case consisting of plate and strut fixed with the maximum possible number of screws had the highest axial stiffness and was the least at risk for fracture since it had the lowest plate stress, second-lowest screw stress, and third-lowest strut stress. Conversely, Cases 2 and 9 had the lowest axial stiffnesses, which could potentially permit some interfragmentary motion for enhanced fracture healing [23]. The comparison study of normal tibiofemoral joint and knee osteoarthritis is done to analyse the displacement, stress and strain values. Magnetic resonance imaging (MRI) is thought to be an inexorably essential instrument for in vivo investigations of musculoskeletal biomechanics. Magnetic resonance images were obtained for two subjects in the age group of 40-45 years. FEA is done using ANSYS 14 software to determine displacement, stress and strain values. Finite Element Analysis (FEA) result includes the stresses and strains induced in the knee articular cartilages and meniscus during single-leg stance. Displacement, stress and strain values for OA knee are higher than the normal knee joint. Hooke's law of modulus of elasticity is verified in this work. Then the finite element model (FEM) is validated through geometrical measurements such as joint space width cartilage thickness and meniscus thickness [24]. It is generally assumed that this process of cartilage degeneration is due to changes in mechanical loading after meniscectomy. Load induced cartilage damage is characterized as either type (1)—damage without disruption of the underlying bone or calcified cartilage layer—or type (2), subchondral fracture with or without damage to the overlying cartilage. To investigate that we applied an axisymmetric biphasic finite element analysis model of the knee joint. In this model, the articular cartilage layers of the tibial and the femoral condyles, the meniscus and the bone underlying the articular cartilage of the tibia plateau were included. The model was validated with data from clinical studies, in which the effects of meniscectomy on contact areas and pressures were measured. It was found that both the maximal values and the distributions of the shear stress in the articular cartilage changed after meniscectomy and that these changes could lead to both type (1) and type (2) cartilage damage. Hence it likely that the cartilage degeneration seen after meniscectomy is initiated by both type (1) and type (2) cartilage damage [25].

The finite element (FE) analysis and modelling of square concrete-filled steel tube (CFST) members subjected to a flexural load. The finite element model was verified by comparisons of computational solutions with experimental results for three different types of concrete. The flexural capacity increases by only 12% when the compressive strength of the infilled concrete increases from 60 MPa to 100 MPa, hence showing a marginal effect [26]. A numerical simulation model using finite element analysis. It could help to avoid failure and to save machining times by predicting the machining parameters such as cutting forces, chip formation, and temperatures distribution. The result is found that there is very good agreement between the simulated values and experimental tests. It concludes that the finite element model represents the real key to reduce the cost of manufacturing in terms of machining time saving and extend the duration of the cutting tool life [27]. The aim of this research was to study the distribution of contact stresses in prosthetic knee joints made out of polyethene chopped carbon fibre composite and conventional polyethene. Commercially available software (ANSYS 8.1) was used in numerical experiments. The effect of the sagittal radius, flexion angles and external load on stresses in the joint were investigated in numerical experiments. The stresses level at the interface of the tibia and femoral is lower for polyethene chopped carbon fibre and alumina ceramic combination compared to polyethene and alumina ceramic [28]. The purpose of this study was to validate the use of the recovery response for mechanical characterization of cartilage in a controlled, ex vivo environment. To do so, confined compression creep and recovery tests were conducted on cartilage explants (N=10), and the resulting mechanical properties from both the creep and recovery phases were compared. No statistically significant differences were found in the mechanical properties between the two phases, reinforcing the hypothesis that unloading (recovery) may be a good surrogate for loading [29] and to develop a new hybrid knee implant which combines a polymer-composite (CF/PA-12) with an existing commercial implant system (P.F.C.® Sigma™) made from stainless steel. This hybrid implant is expected to alleviate stress shielding and bone loss by transferring much more load to the femur compared to conventional metallic implants. Results of the FEA simulations showed that the CF/PA-12 lined femoral component generated almost 63% less in peak stress compared to the regular stainless steel component, indicating more load transfer to the bone and consequently alleviating bone resorption [30]. The study shows for the first time the loads experienced by all four major ligaments of the knee, and the minimum loads in the menisci in response to in-vivo motions. The ISL and robotic test platform allow determination of the loads on the four major ligaments and the two menisci in the joint. This study shows for the first time the loads experienced by all four major ligaments of the knee, and the minimum loads in the menisci in response to in-vivo motions. Results showed similar loading patterns between animals but with some quantitative differences [31]. A sensitivity study was undertaken to evaluate the model response due to some of the model parameters and to gain a better understanding of the function of the elements in the model. A three-dimensional analytical model of the knee joint is presented, taking into account the geometry of the joint surfaces as well as the geometry and material properties of the ligaments and capsule. It is concluded that the predictions of the model agree well with experiments described in the literature [32] and to evaluate the associations between knee muscle strength (MS) and falls, controlling for knee joint proprioception, varus-valgus knee joint laxity, and knee pain, among patients with knee osteoarthritis (OA) reporting knee instability. The methods used for Maximum knee extension and

flexion strength measurement is done by iso-kinetically. Additionally, proprioception, varus-valgus laxity, and pain were assessed. After Conducting the tests, it was concluded that high knee extension and flexion muscle strength decreased the risk of falls in patients with knee OA and self-reported knee instability [33].

Based upon the re-injury to a recently rehabilitated or operated knee is a common occurrence that can result in significant loss of function. Finally Concluded that they have reviewed a broad spectrum of knee stability measures designed to detect anterior-posterior and rotational knee instability [34]. With the information of determining the effect of the whole-body vibration training program (WBVT) in comparison with conventional training (CT) program on knee proprioception and postural stability after anterior cruciate ligament (ACL) reconstruction. The methodology used is Twenty athletes with unilateral ACL reconstruction were randomly assigned in two groups; WBVT and CT, all participants received 12 sessions of WBVT or conventional training. Finally it was concluded that whole-body vibration training improved proprioception and balance in ACL reconstructed athletes [35]. To assess the impact of MRI in selecting or excluding cases which genuinely require arthroscopic surgery. To know whether routine MRI is required pre-operatively in all cases with positive clinical findings. The conclusion which was made after the study is Clinical examination is more sensitive, specific and accurate in the diagnosis of ACL. MRI is more sensitive but less specific for meniscal injuries. Clinical examination for cruciate injuries can surpass the MRI findings. Arthroscopy can be performed without MRI in single lesion injuries. However, MRI will play a role in meniscal injuries or doubtful cases [36]. From the study of this paper, it was obtained that it was on ligament grafts length used in an anterior cruciate ligament (ACL). The methodology used is ninety-one adult cadavers were studied. Patellar ligament (PL) length, ACL length, ACL width and the maximum femoral epicondylar width (FECW) were measured. Finally, it was concluded that an individual's FECW could be used to predict ACL length pre-operatively [37]. Fatigue is known to influence dynamic knee joint stability from a neuromuscular perspective, and electromechanical delay (EMD) plays an essential role as the feedback activation mechanism that stabilizes the joint. The final discussion was, the current study indicates that soccer-specific fatigue significantly increases the EMD post fatigue, compromising neuromuscular control required to stabilise the joint, in female youth soccer players. These effects were significantly more significant in the youngest (U13) age group compared with the older (U15 and U17) age groups [38]. The work was based upon the electrical stimulation (ES) and magnetic stimulation (MS), applied peripherally, may be used to elicit muscle contractions to increase muscle hypertrophy, increase muscle strength and reduce knee laxity in rehabilitation following injury. It was concluded that both peripheral stimulation interventions suggested a beneficial trend during strength training by allowing the production of additional repetitions at the point of muscle failure when it was not possible to continue with voluntary activation alone [39]: the injury prevention, recognition of common injuries in sports and causes damage. The aim of this study was to investigate the prevalence and mechanisms of injuries in male professional beach soccer players in Yazd province. The methodology used was to survey of 50 soccer players and data was analysed using the chi-square test. It can be concluded finally that most of the injuries experienced in this field of sport are due to lack of leg and shin covering [40]. To provide a general review of the computational models used in the analysis of the mechanical function of the knee joint in different loading and pathological conditions. It is also discussed about geometry- reconstruction procedures, as well as some critical issues in finite element modelling, are also discussed [41]. To evaluate the effectiveness of the arthroscopic procedures for the symptomatic discoid meniscus. This is because discoid meniscus is often revealed clinically during childhood. However, many patients with discoid meniscus remain asymptomatic and present late. After the study, it was concluded that treatment of symptomatic torn discoid meniscus by the arthroscopic procedure is safe, simple with minimal operative trauma and fewer complications [42].

By the literature survey, the paper concludes that COMPUTATIONAL and EXPERIMENTAL methods plan an essential role in designing reliable prostheses. There are many methods for a knee implant, but TOTAL KNEE IMPLANT(TKR) plays an essential role in the knee replacement process. Using a statistical method can be used to achieve a required reliable of welded joints concerning fatigue as a design criterion. The metal Ti-6Al-4V is determined as highly BIOCOMPACTABLE metal than compared to ceramics, stainless steel and other carbon metals. Since the metal Ti-6Al-4V has high strength, it is difficult to machine alloy using conventional machining. Since the process, AWJM is conducted under less heat affect zone and higher material removal, TITANIUM is possible to enhance machining using this process. Dry machining should be avoided for saving tool life and surface texture of the material. Good surface finishing of TITANIUM can be obtained under WET machining minimum depth of cut, and maximum R.P.M. Electromechanical delay(EMD) plays an important role in knee replacement because it acts like a feedback activation mechanism that stabilizes the joint. The main reason for a knee injury is due to the overweight of the body and increasing age. As the age increases, the strength of the bones becomes weaker, which leads to a knee replacement. The treatment of symptomatic torn discoid meniscus by the arthroscopic procedure is safe. The main cause of leg injury for players is due to lack of leg and shin covering. If the covering is done, then there is a chance to reduce the knee injury by 50%. As Ti-6Al-4V highly has high strength, it is now widely used for knee replacement. Stimulation interventions suggested a beneficial trend during strength training by allowing the production of additional repetitions at the point of muscle failure when it was not possible to continue voluntary activation alone. Femoral epicondylar width(FECW) is used to predict Anterior cruciate ligament(ACL) pre-operatively. Finally, we conclude that high knee extension and flexion muscle strength decreased the risk of falls in patients knee osteoarthritis(OA) and self-reported instability.

Force Analysis of Knee Joint

The Static analysis is used to determine the forces and moments acting on a joint when no motion takes place or at one instant in time during a dynamic activity such as walking, running or lifting an object. A simplified technique is used, such as a free body diagram and limits the analysis in one place. The three principles coplanar force acting on the free-body are identified and designated in the free body diagram. The various forces acting on the knee joint in various motion are as follows:

- Fx - Friction Force
- Fy - Ground Reaction Force
- Fz - Ground To Foot Force

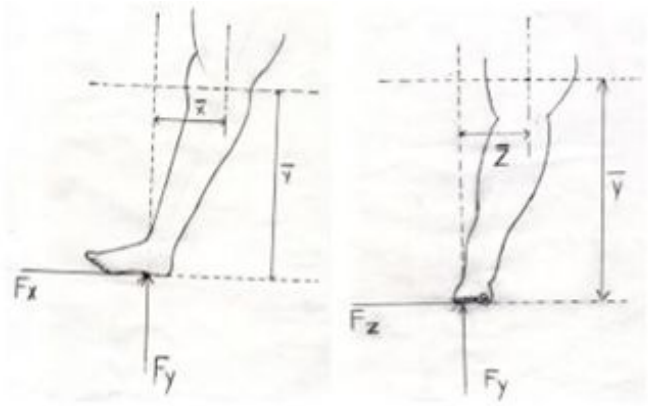


Fig. 1. Free body diagram of the knee joint for case-I.

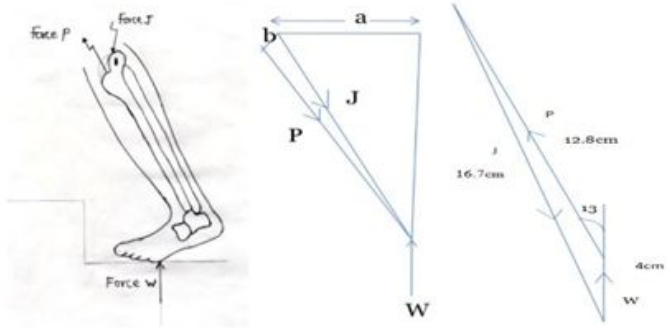


Fig. 2. Free body diagram of the knee joint for case 2.

- X – Perpendicular distance along with Fy
- Y - Perpendicular distance along with Fx
- P - Patella Tendon Force
- J - Joint Reaction Force
- W - Ground Reaction Force
- a-Perpendicular Distance along W
- b-Perpendicular Distance along with P

The case I

When the total weight of the body is acting over a single knee joint in a straight position. In the first case, the two coplanar forces (Fx and Fz) acting on the foot are calculated by measuring the distance from the line of action of a force from the ground by considering the vertical force Fy as a weight of the body. The external force system acting on the tibia consists of the three ground-to foot forces (Fx, Fy, and Fz). Fx is the frictional force acting at the foot in the line of progression; Fy is the vertical component, and Fz is the side-to-side ground-to-foot force. In the sagittal plane of the knee, the turning moment Mz can be estimated from Mz = Fy × X and Fx × Y. The lever arms X and Y are calculated from the knee and the coordinates for the centre of the pressure of the foot. In the coronal plane, Knee moment Mx is calculated from Mx = Fy × Z and Fz × Y.

Case II

During walking or lifting, the leg is in an inclined position and total weight of body acting on the ankle. For the second case, an example illustrates the application of the simplified free-body technique for coplanar forces to the knee. The techniques used to estimate the minimum magnitude of the joint reaction force acting on the tibiofemoral joint of the weight-bearing leg when the other leg is lifted during stair climbing. As per the literature studied the two main forces acting on the joint during walking and stair lifting position are patella tendon force (P) and joint reaction force (J) with the ground reaction force (W) as per the weight of the body. The forces acting on joint has been calculated from the vector diagram, and the distance up to knee joint from the vertical force is measured practically are shown. $\sum M=0$ $W\times A - P\times B = 0$ $W\times A = P\times B$

Medical use or purpose

Knee replacement surgery is most commonly performed in people with advanced osteoarthritis and should be considered when conservative treatments have been exhausted. Total knee replacement is also an option to correct significant knee joint or bone trauma in young patients. Similarly, total knee replacement can be performed to correct mild valgus or varus deformity. Valgus severe or varus deformity should be corrected by osteotomy. Physical therapy has been shown to improve function and may delay or prevent the need for knee replacement. Pain is often noted when performing physical activities requiring a wide range of motion in the knee joint.

Variations in manufacturing

Variations in the manufacture and surgical preparation for knee replacement occur between cemented and uncemented components, between resurfacing the patella or not, and between denervating the patella using electrocautery or not. Cemented-fixation may be more vulnerable to future aseptic loosening than the cement-less technique. Retaining the posterior cruciate ligament (PCL) has been shown to be beneficial for patients. Removal of the PCL has been shown to reduce the maximal force that the individual can place on that knee. Typically individuals who have the PCL removed will lean forward while climbing in order to maximize the force of the quadriceps. A variation in the total knee replacement procedure is to permit movement in the prostheses using a polyethene insert, and an approach called mobile-bearing total knee arthroplasty. There is no strong evidence that this approach improves knee function, mortality, number of adverse effects, or amount of pain compared to a fixed bearing approach for total knee replacement that retains the PCL. Minimally invasive procedures have been developed in total knee replacement that does not cut the quadriceps tendon. There are different definitions of minimally invasive knee surgery, which may include a shorter incision length, retraction of the patella without eversion (rotating out), and specialized instruments. There are few randomized trials, but studies have found less postoperative pain, shorter hospital stays, and shorter recovery. However, no studies have shown long-term benefits.

Softwares generally used for analysis on total knee replacement: Medical simulation, or more broadly, healthcare simulation, is a branch of simulation related to education and training in medical fields of various industries. Simulations can be held in the classroom, in situational environments, or spaces built specifically for simulation practice.[1] It can involve simulated human patients - artificial, human or a combination of the two, educational documents with detailed simulated animations, casualty assessment in homeland security and military situations, emergency response, and support virtual health functions with holographic simulation. In the past, its primary purpose was to train medical professionals to reduce error during surgery,

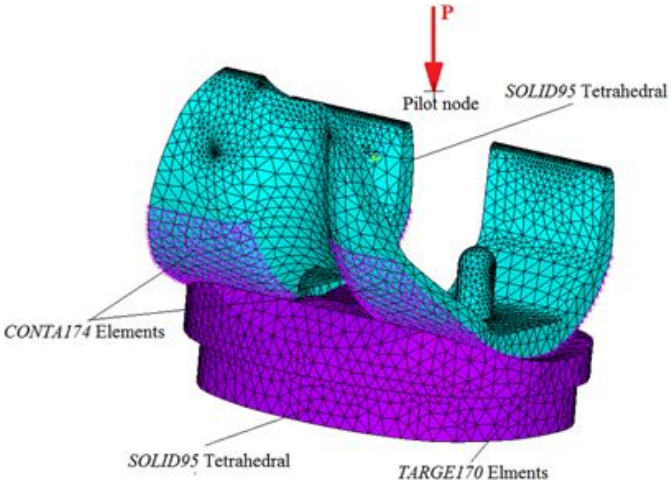


Fig. 3. The meshing of the knee cap.

prescription, crisis interventions, and general practice. Combined with methods in debriefing, it is now also used to train students in anatomy, physiology, and communication during their schooling. These are some of the screen-based simulation software for analysis of bones

- ACLS Simulator
- Anatomy Module
- Anesthesia Simulator
- Anesthesia SimSTAT - ASA/CAE Healthcare
- CardioSim
- MicroEKG
- Neonatal Simulator

These are high fidelity simulators which can enable us to examine the minute change in bone moments.

By using ANSYS software:

The finite element method (FEM) is a widely used numerical technique to analyse stress-strain states in various biomedical devices and prosthetic bone joints, in particular. Accurate geometric models of the tibial and femoral components of artificial knee joint were constructed using ANSYS software. Two-dimensional diagrams of the femoral and tibia components. The finite element model was generated by meshing the solid model brick elements. The tibial component was constrained in all degrees of freedom at its lower surface. The femoral component was rigidly fixed. the compressive load was applied to the femoral component at the bearing points at different flexion angles.

Modelling of all the components of the knee joint, i.e., Femur(thigh) bone, the knee cap(patella) and the Shinbone or otherwise called Tibia along with Fibula which stabilizes the human leg are modelled and designed in Solidworks software. All the designed bones and the knee cap are further assembled in the same software. Now the analysis is conducted on the knee cap by assigning three different materials such as Stainless Steel, Ceramic and The Titanium alloy (Ti-6Al-4V).

Modelling & Assembly:

All the parts (Tibia, Kneecap, Femur and Patella) are initially modelled in the Solidworks software and then assembled in the same.

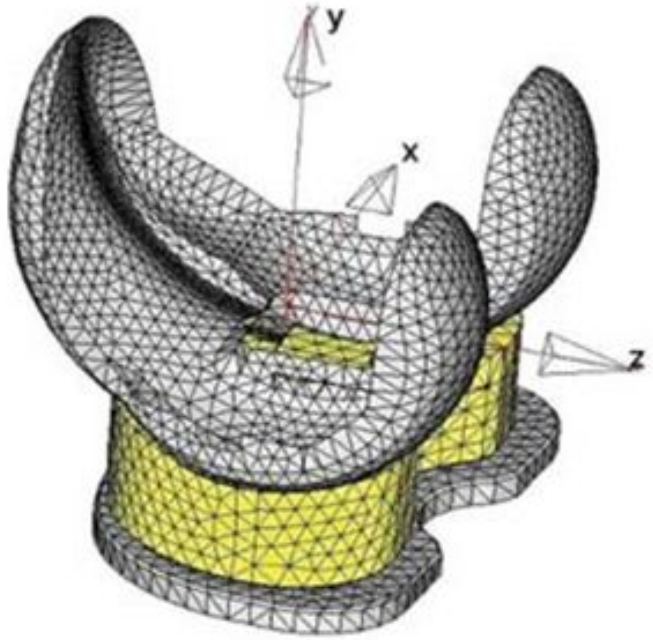


Fig. 4. The action of forces on the knee cap.

Design of the knee cap and Patella

For the design of kneecap, we selected the front plane and drew the front view of the cap with the help of line and spline commands. Later the drawn sketch is selected, and the revolved it through 180°. We get the solid object. However, we require a surface model. So, in order to get it, we use the shell feature which removes the material from the object and leaves the kneecap.

Design of Bones (Femur & Tibia)

The design of a bone is a very complicated job and requires surface modelling techniques. Because the surface of the bone contains very intricate contours.

Assembly

It involves bringing in all the individual parts together and then assembling by giving suitable mates. The lower portion of the upper bone(femur) is in contact with the inner surface of the kneecap. The outer portion of the knee cap is an inmate with the upper portion of the spacer, which acts as a shock absorber. The lower portion of the plate is in fixed contact with the Tibia bone or otherwise called as the shin bone.

Analysis

After completing the assembly in Solidworks software, we import the same file into Ansys software for conducting the analysis. This can be done first by saving the Solidworks file in ".IGS" format. Now the file can be opened in Ansys software with the help of the database. Now we apply the suitable materials to the different parts, and then the file meshes. Now the meshed file is taken for analysis. As mentioned above the loads are applied, and the constraints are given by selecting the respective surfaces, and we run the study. The element size for meshing is taken as fine for accurate results even though it takes a bit time, and the element shapes are taken as a tetrahedron, and the boundary conditions are as follows:

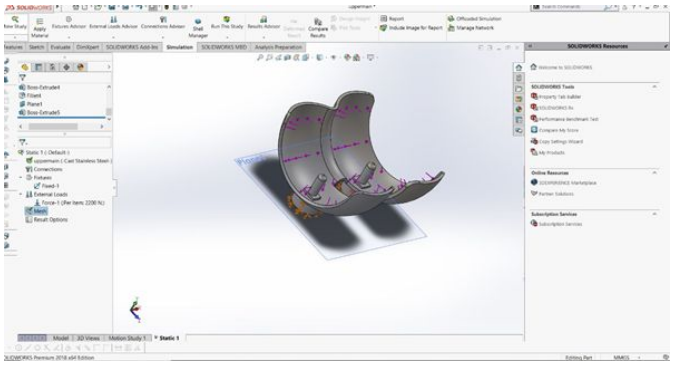


Fig. 5. Applying constraints to stainless steel knee cap.

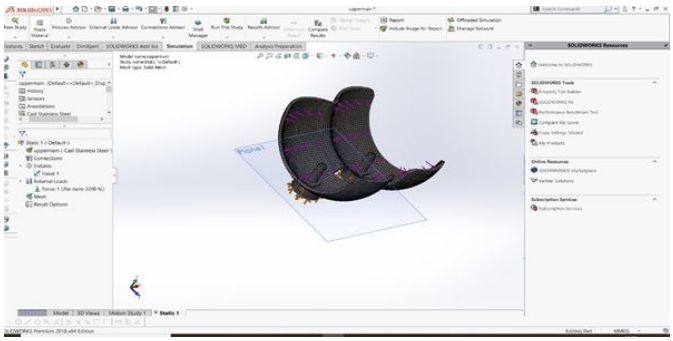


Fig. 6. The meshing of the stainless steel knee cap

Boundary Conditions:

Load was applied in the form of force. While standing axial load is one who acts and thus needs to be applied. Maximum load should be applied for testing the prosthesis as we should think of worst-case scenario (In case of jumps or jerks etc.,). In this study, we have tested the prosthesis at a load of 2200N when the leg is in a straight position which is the maximum load which is approximately three body weights considering average weight of an individual to be 60-65 kg. We have checked the stress pattern. The bone assembly of (Tibia, Knee cap, Femur and Patella) have some constraints such as the inner part of the kneecap is fixed with the bottom portion of the femur bone. The Outer surface of the kneecap is in rolling contact with the upper part of the plate which is fixed to the upper portion of the tibia or the shin bone. The following are the figures which are designed in Solidworks software:

From this analysis, we conclude that the Titanium alloy gives us the best results, and also we infer that Titanium is the best biocompatible material. Hence we go for Titanium-based alloy. The analysis figures are shown below:

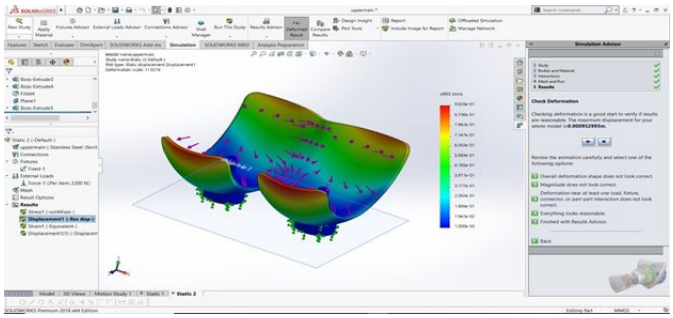


Fig. 7. Deformation of Stainless steel material knee cap.

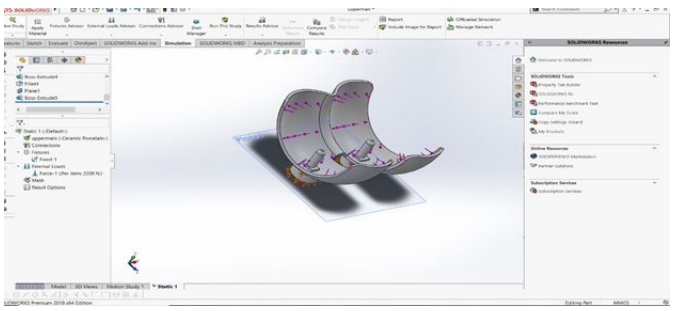


Fig. 8. Applying constraints for ceramic knee cap.

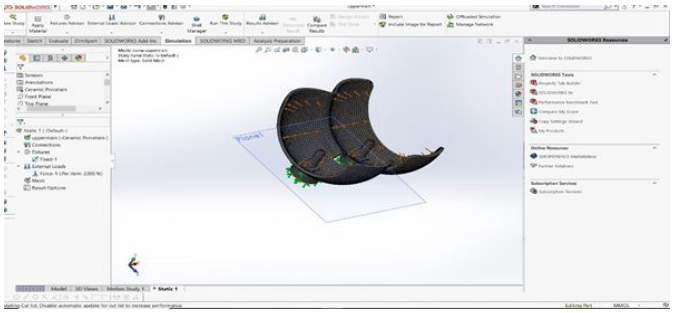


Fig. 9. The meshing of the ceramic knee cap.

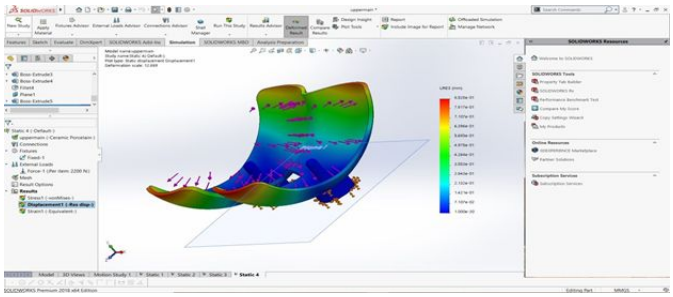


Fig. 10. Deformation of Ceramic knee cap.

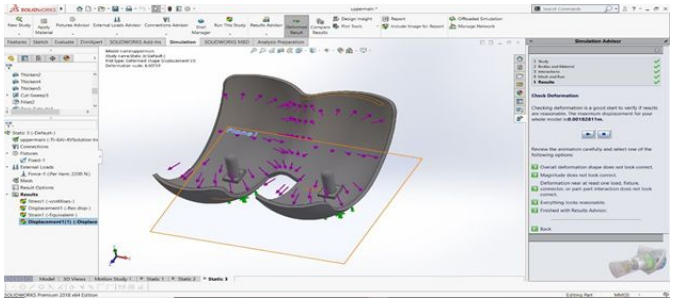


Fig. 11. Applying constraints to Titanium alloy knee cap.

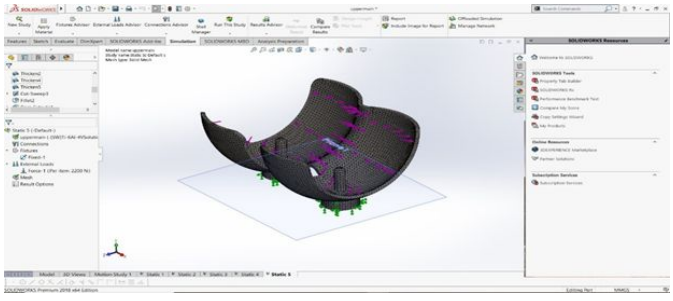


Fig. 12. The meshing of Titanium alloy knee cap.

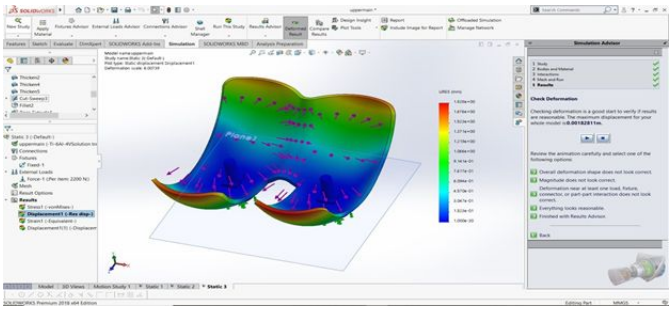


Fig. 13. Deformation of Titanium alloy knee cap.

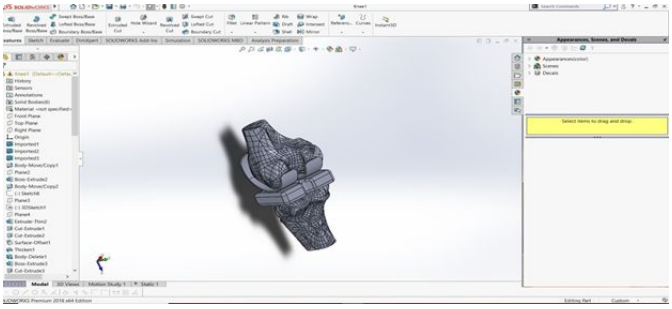


Fig. 14. The meshing of Femur bone, Tibia bone and Titanium alloy knee cap.

Results and Discussions:

By the study of the method of Total Knee Replacement (TKR), the implant is provided at the joint due to accidental injuries or diseases. The analysis is performed on knee cap with three different materials like Ti-6Al-4V, Stainless steel and ceramics. The knee cap made up of Stainless steel shows more deformation than Ti-6Al-4V and has a yield strength 1.723MPa under complex loading, as shown in following figure 15. The knee cap made up of ceramics has large deformation than Ti-6Al-4V and Stainless steel, shown in the below fig 16. The knee cap made up of Ti-6Al-4V has less deformation and shows high yield strength 8.274MPa under complex loading shown in below fig 17.

After placing the Ti-6Al-4V knee cap in knee joint show is in Figures 18 and 19.

This study consists of total deformation of femur and tibia bone along with knee cap where the maximum load is acting on femur bone, and minimum load is acting on tibia bone. By this we can understand that impact of the load is more on femur bone than tibia bone.

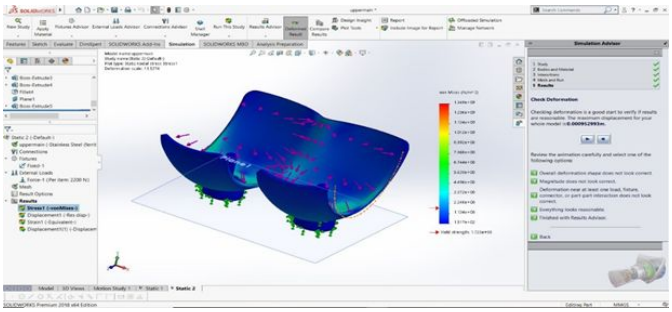


Fig. 15. Deformation of Stainless steel knee cap.

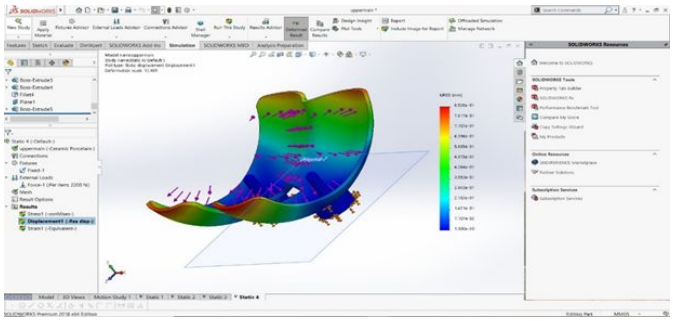


Fig. 16. Deformation of Ceramic knee cap.

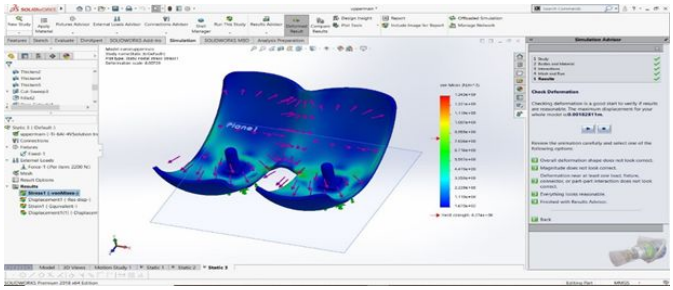


Fig. 17. Deformation of Titanium alloy knee cap.

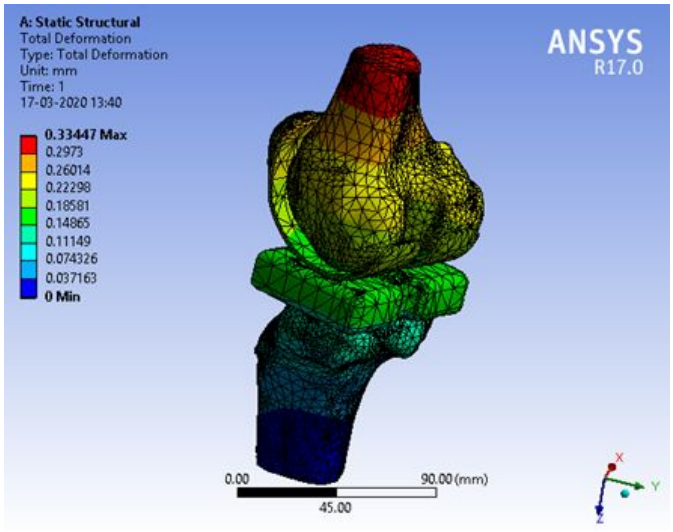


Fig. 18. The analysis was done on the knee cap along with femur and tibia bones.

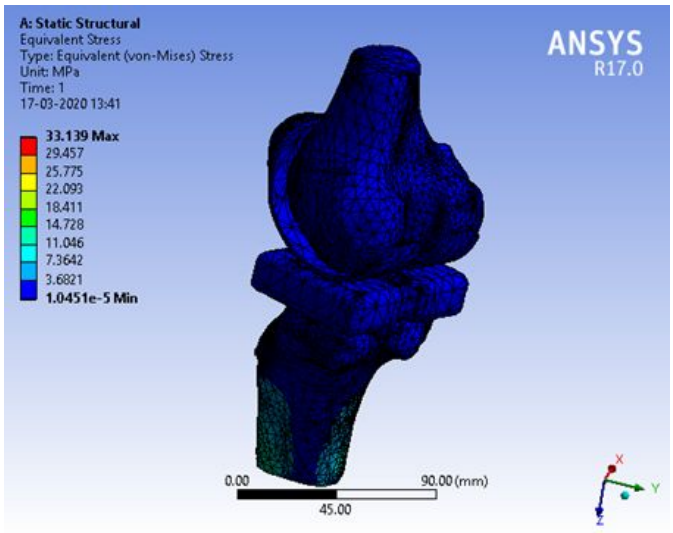


Fig. 19. Von-mises stress on the knee cap.

Conclusion and Future Scope

Finite element analysis proved as one of the efficient techniques for evaluation of the performance of prosthesis with different materials under day to day loading conditions. This study and research work can conclude the facts: The material Ti-6Al-4V is selected based on the results that are obtained from the analysis on the kneecap by assigning three different materials such as Ti-based alloy, Ceramic and Stainless Steel.

- It is clear from the results that the Titanium Alloys (Ti-6Al-4V) is the best material of choice for knee implant because it shows the minimum Von-mises stress at the extreme loading conditions than the other materials.
- The result of the analysis showed us that Titanium could withstand the loads that fall on the knee bone better than that of other materials. Also, we know that Titanium is the strongest and the best Biocompatible metal that can be used.
- Although Stainless Steel and Ceramics are less costly compared to Titanium alloys, it is worth spending more initial cost on Titanium-based Kneecap because of its biocompatible nature and its strength to support the loads that fall on the Knee joint.

The future scope from work is framed as follows:

- Practical and clinical implementation should be done.
- Vibrational and Thermal analysis can be done.
- Research should be done on other materials which can be better than titanium alloy for knee implant.
- Dynamic analysis should be considered for a better understanding of knee mechanics.

Conflict of Interest

Authors declare no conflict of interests.

Funding

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Ethics committee approval

The Institutional Ethics Committee approved the study.

Patient informed consent

Not applicable.

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