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Finite Element Modeling and Analysis of Prosthetic Knee Joint

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ABSTRACT: As a human getting older there are so many health related problem occurs at the older age naturally, and they are not so easy task to cure all the diseases occurred. But also some of them are curable, for such curable condition here discussed a knee joint issue that has the disease called Degenerative arthritis it's a condition where occurs in-between the femur and tibia parts are affects the line cartilage of the joint which results drastic harm to the joint leads to serious injury to the person. This disease affected person can experience severe pain at joint and it resist the knee joint movement which results to the patient unable to walk freely and in some crucial condition patient unable stand and small move also impossible. For this condition it has a solution called the surgery, yes! It has a knee replacement surgery which includes damaged parts are replaced with the prosthetic parts. And the design and modeling of the joint is completely based on the patient's condition at the joint. If the pain is drastic the whole knee joint is replaced, if not for small injuries the coat materials are designed as cap materials for the knee joint. By the available literature its known that the materials are used for this surgery are the bio metals this metals are have main significance in prosthesis. Because these bio metals have the bio compatibility means that they have the properties like high chemical stability, non corrosive and non toxic these are main properties to select the prosthetic material. And where these materials are also have the high stress loading conditions. The modeling and design of the knee joint is done based on available literature source in Solid Edge software and the knee joint is subjected to different body temperature condition to know the thermal behavior. And the materials applied for analyzing purpose are like the whole joint is applied with Structural Steel as first, Polyethylene as second and at third combined material is analyzed means the material applied separately i.e. Aluminum alloy for Femur and Polyethylene for Tibia. And three sets are analyses in software (ANSYS 18.1) to investigate the Total heat flux and Total directional heat flux.

Keywords--Finite element analysis (FEM), Knee Joint, Degenerative arthritis, Total heat Flux, Total Directional Heat Flux.

I.INTRODUCTION

Knee joint is one of the complex structure found in the human body. Where it give support to the whole body weight also it has to be the hardest joint and come up with motility. In otherworld's, due to having high stress at the knee joint leads to some injuries ,as well as the development of osteoarthritis, that leads the trauma at joints and complication in walking. Presently, total knee replacement (TKR) is used with assurance for clinically effective modality for the release of maximum pain connected with rheumatoid arthritis at the knee joint to restore physical function in patients. On the other side, it generally requires replacement and recovery surgeries. Therefore, it's essential to reduce the rate of replacement surgery by providing more durable knee prostheses which can be derived by improving implant structural design and materials[1].Prosthetics were existed from the times of ancient Egyptians and they have many application like for the clear appearance and most importantly in early days of ancients and they believe their spiritual sense of being whole. There spirituality is like to bury the amputed parts until the human last his life and it will be kept as it is before the prosthetics were generated. And one of the best example still present in Egypt i.e. mummies are of 18th dynasty of Egypt were still found with prosthetic toe is made of the leather and wood .For the generation of this prosthetics take credits for the civilization of Greek and Rome[2].

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Figure 1. View of Femoral and Tibia

Figure 2. View of Diseased Knee Joints

There is wide scope in designing prosthetics by adoptive mechanisms for the opening and closing the fingers if the arm get amputed and this control system will keep never ending challenge for researchers [3].Computer aided drawing/design and manufacturing by which the by these software's the new manufacturing appeals that performs the automated machining with accuracy [4].Design procedure or the mathematical model "Theory of inventive problem solving (TRIZ) plays an important role [5].the software called MIMICS and it is software which converts the real CT scan images into a 3D model and the procedure they followed is that importing the images CT scan to file by changing the orientation of the images we get the accuracy in images by the MIMICS software[6].In early days the authors used to draw the free hand sketch from the pelvis region end to the edge of the foot ,and they were used chain kinematics to model the lower edge and its of to the foot position though trunk interaction or the pelvis[7].They used the steady state thermal analysis of the shell tube of shell and tube to know the heat transfer of different material they mentioned Steel1008, Aluminum and Copper for different parts such as the tubes, baffle plates and shell of the material that to be assigned[8].The some author is going to investigate the temperature distribution between the material N 155 and Inconel718 and they wanted check the suitable material having the best thermal properties[9].

II. DESIGN CONSIDERATION OF KNEE JOINT

The advancement of the cutting edge all out knee arthroplasty[14] can be traced all the way back to the 1960s. The polycentric knee planned by Frank H. Gunston[13] presented the utilization of two solidified polyethylene tibial segments articulating on two established femoral parts. Also, particular instrumentation was utilized to embed the prosthesis. The presentation of a dependable obsession specialist, along the edge of a metal on engineered pitch verbalization, LED to an angry advancement of styles in knee arthoplasties[15]. With the presentation of a huge number of various prostheses with fluctuating levels of tibiofemoral congruity and various ways of thinking concerning the penance of the front and back cruciate tendons, various strategies for assessing all out knee arthroplasty execution were created by specialists.

III. 2D AND 3D MODELING

Getting the real images of knee joint is quite tough task but in this research paper G Mallesh and Sanjay .S.Jthey used the software called MIMICS and it is software which converts the real CT scan images into a 3D model and the procedure they followed is that importing the images CT scan to file by changing the orientation of the images we get the accuracy in images by the MIMICS software .And it is the automatic software were it and automatically creates the coronal and saggital radius of the imported images. And its then very easy to proceed with the 3D images that we get from software by the 3D images its easy to possible to create the 2D images. And this collected data is used dimensions of femur and tibia[7].

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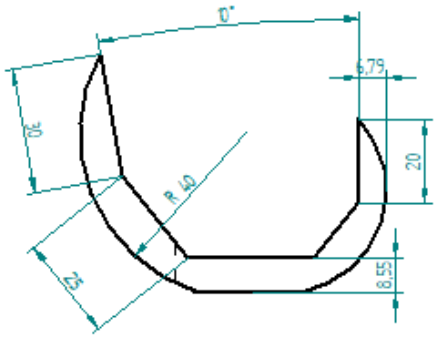

Figure 3. 2D Model of Femur

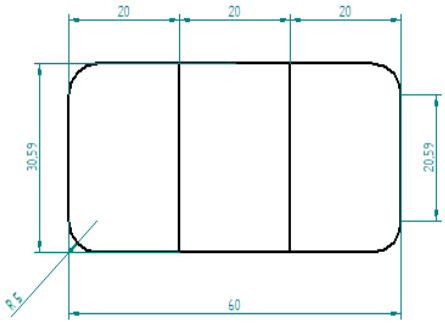

Figure 4. 2D model of Tibia

These femoral and tibial components are developed by the support of the CAD/Cam systems,Computer aided drawing/design and manufacturing by which the by these software's the new manufacturing appeals that performs the automated machining with accuracy . For this type of accuracy Chi-Mun Cheah et.al. proposed CAD ,rapid prototyping and rapid tooling technique ,by this they prepared a mould and it is of cast material[5].

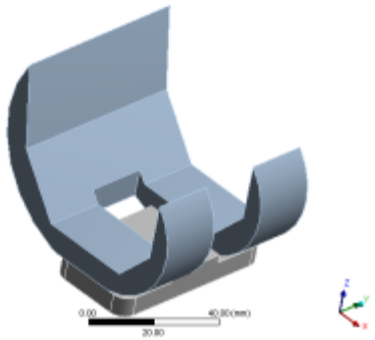

Figure 5. 3D Model Assembly

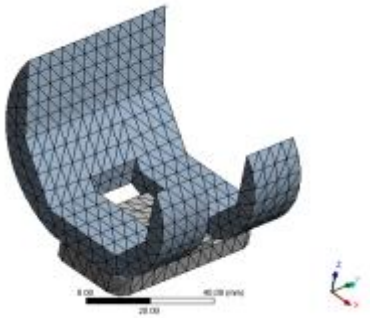

Figure 6. Mesh Model of knee joint

IV.FINITE ELEMENT MODEL OF PROSTHETIC KNEE JOINT

Finite element analysis[10] is the process of simulation of part or assembly under given conditions so that can be assessed using the Finite element method. Under this Thermal analysis[11] in FEA which provides useful information about heat flux, directional heat flux and temperature. Heat flux[12] is the rate of heat energy transferred through the surface or material.

V.RESULT AND DISCUSSION

Total heat flux and Directional heat flux were determined here by applying different type of temperature i.e. 5^0C, 10^0C, 15^0C, 20^0C, 25^0C, 30^0C, 35^0C, 40^0C, 45^0C, and 50^0C where this temperatures are added based on human body condition i.e. where human can survive the maximum and minimum temperature although for analysis purpose some low and high temperatures also added. So now the materials selected for the analysis are a)Structural steel for both tibiofemoral components b)Polyethylene for both tibiofemoral components. c) Aluminum alloy and Polyethylene for Femur and Tibia respectively.

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[A] Effect Of Temperature On Total Heat Flux (THF) For Different Materials

I. Structural Steel (SS).

(a) Total Heat Flux at T=5^{0}C

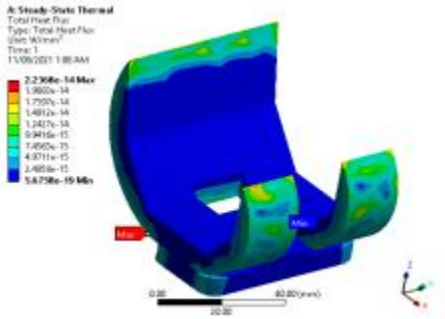

Figure 7: THF for Structural steel T=5^{o}C

(b) Total Heat Flux at T=50^{0}C

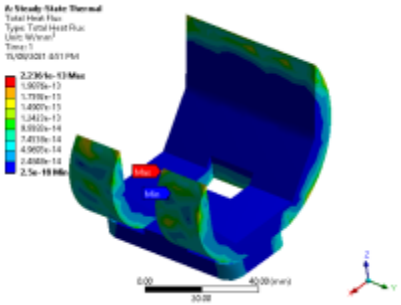

Figure 8: THF for SS material at T=50^{o}C

II. Polyethylene:

(a) Total Heat Flux T=5^{0}C

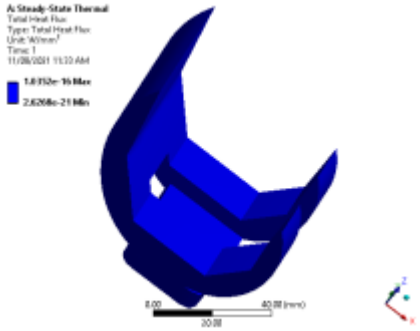

Figure 9: THF for Polyethylene at T=5^{o}C

(b) Total Heat Flux T=50^{0}C

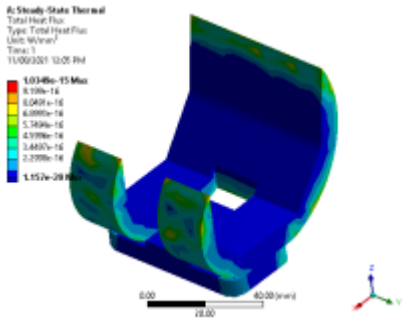

Figure 10: THF for Polyethylene at T=50^{o}C

III. Aluminum Alloy for Femur and Polyethylene for Tibia

(a) Total Heat Flux T=5^{0}C

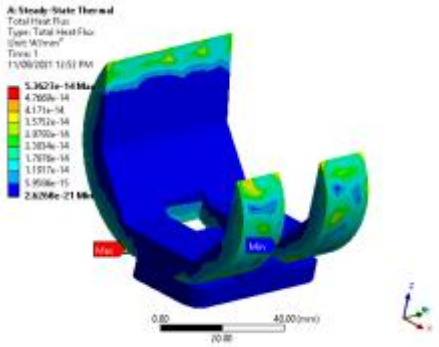

Figure11:THF for Al. alloy and Polyethylene

(b) Total Heat Flux T=50^{0}C

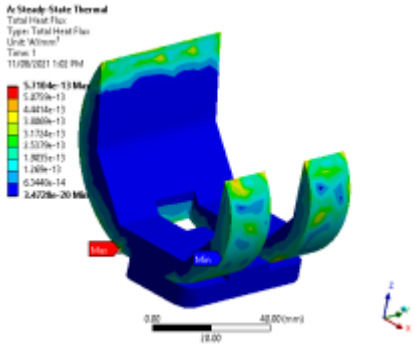

Figure 12:THF for Al. alloy and Polyethylene

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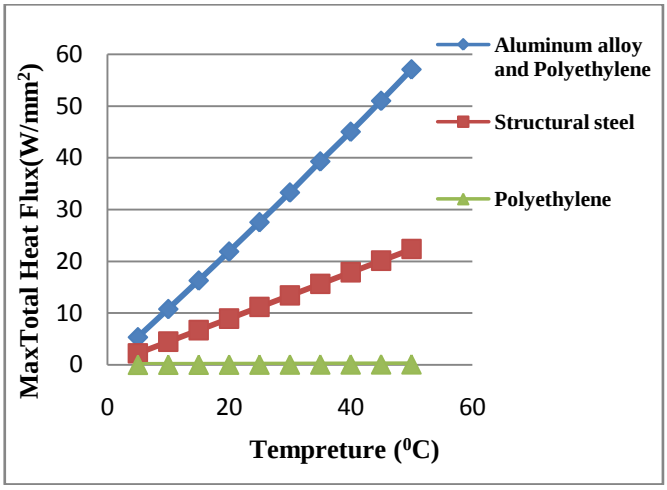


Graph 1: Maximum Heat Flux for Different Material.

The graph shows the variation in the THF for the structural steel, polyethylene and combination of aluminum alloy and polyethylene .Where we can observe very minute changes in polyethylene material i.e. 1.0352e-16 and comparatively the structural steel material have the moderate changes in heat flux and the combined material has the highest range of Total heat flux i.e. 5.3627e-14W/mm^2.And this result is recorded as the highest value of the THF.

[B] Effect of Temperature on Total Directional Heat Flux For Various Materials.

[1] Total directional Heat flux for the Structural Steel at T=5^{o}C

At X-axis

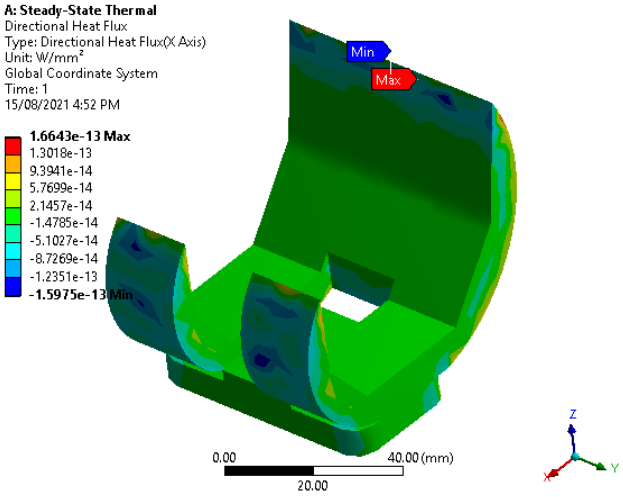
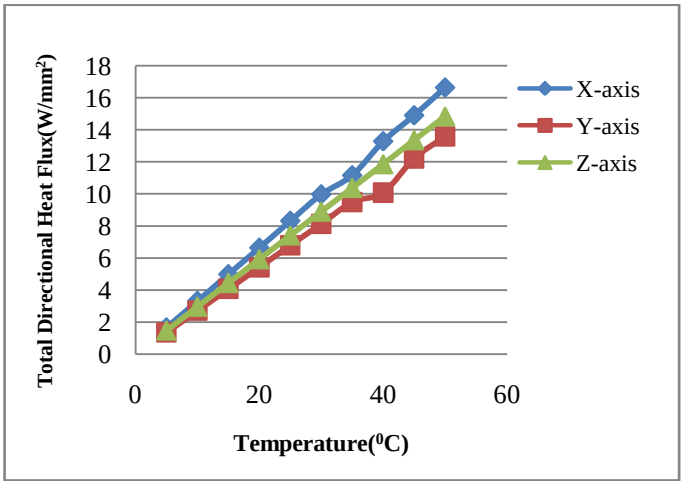


Figure 13: TDHF in X-axiss



Graph 2. Directional heat flux for Structural steel material.

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From the above graph its clearly shown that the heat flux is generation is high at the X-axis followed by Z-axis and at last the Y-axis is showing that comparatively less generation of Total heat flux .

[II]Total directional Heat flux for the Polyethylene at T=50°C
At Y-axis

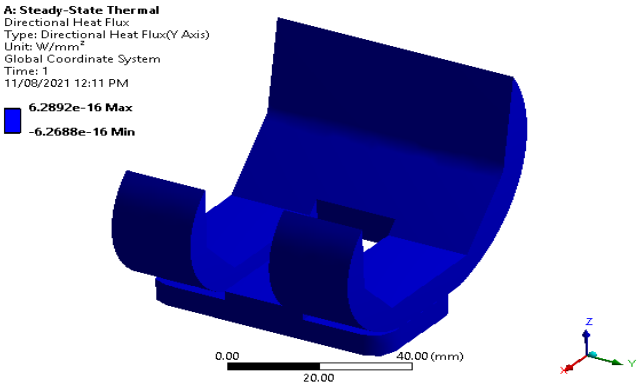
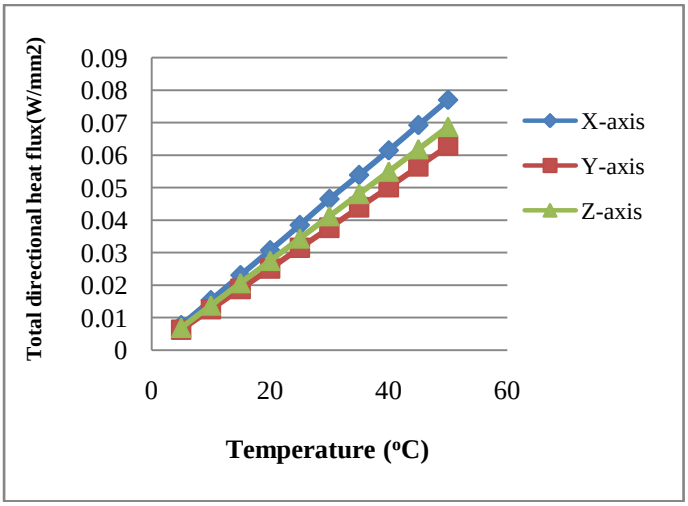


Figure 14: TDHF in Y-axis



Graph 3 :Directional heat flux for the Polyethylene material.

By the above graph it indicates that Total Directional Heat flux is more at the X-axis and then followed by Z-axis having the high heat flux compared to Y-axis.

[III] Total directional Heat flux for Al. alloy (femur) and Polyethylene (Tibia) at T=5°C
At. Z-axis

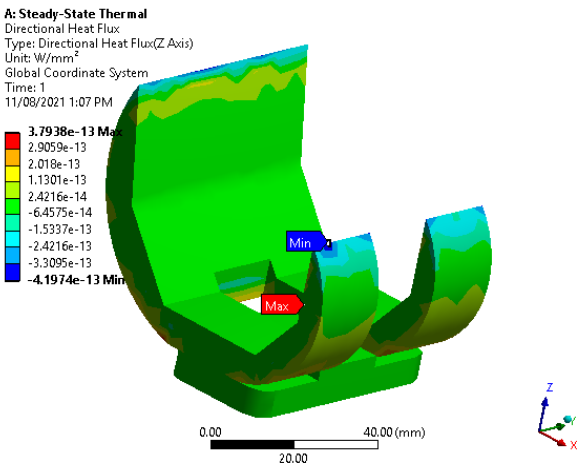


Figure 15: TDHF in Z-axis

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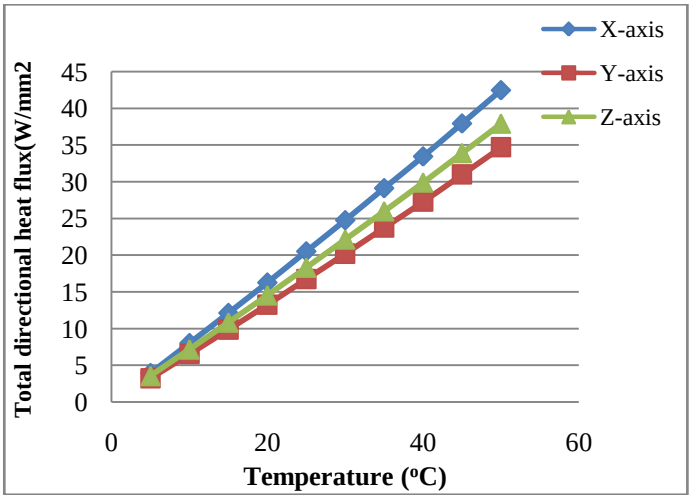

Graph 4:.Directional heat flux for the Combined material Al .alloy(Femur) and Polyethylene(Tibia) material

The shown above graph which tells us that Total Directional Heat Flux is generated is highest at the X-axis lowest at the Y-axis and between this values Z-axis having moderate TDHF

VI.CONCLUSION

As temperature rises the Total heat flux also rises for all the materials that we have assigned. Initially the whole assembly i.e. complete knee joint, parts includes Femur and Tibia are assigned with Structural Steel for first Analysis, Polyethylene for second and for third analysis material assigned separately i.e. Aluminum alloy is applied for Femur Polyethylene for tibia. Then these set of materials are analyzed with different body temperature from 5°C to 50°C and by analyzing the results we got the best results at the third analysis i.e. the joint with Aluminum alloy as the femur part and Polyethylene as Tibia. And by the results and analysis its clearly shown that Total Directional Heat Flux is very high at the X-axis for all the materials that we assign earlier. And its recorded as Y-axis of the material has the less heat flux generation.

Future Work

- For our study we only choose finite element analysis and the study can be extended to fluid flow analysis using CFD.
- The experimental tests can also conducted.

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