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FEA and Experimental Investigation of Prosthetic Knee Joint

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Abstract

The aim of this study is to look at how stresses are distributed in a polyethylene-based prosthetic knee joint. Ansys 18.1 software is used for finite element analysis. In experimental studies, the effects of sagittal radius, flexion angle, and external load on knee joint stresses were investigated. The prosthetic knee joint is created as a 2D model using parameters like sagittal radius and flexion angles in design modeling software. The experimental work has been carried out in a polariscope machine setup, The photo elastic model is tested in different loading conditions and finds stress in that model. Finally, results are validated experimental results with FEA results.

Keywords: *Finite element analysis, Polariscope, Knee joint, Tibial, Femur, Flexion angle, Sagittal radius.*

1.0 Introduction

The knee joint is also one of the human body's several complicated parts. It must be the strongest joint and provide mobility because it supports the entire body weight. On the other hand, the knee joint is affected by accidents such as acute injuries and the development of osteoarthritis, which causes joint pain and difficulties walking [1]. Total knee replacement (TKR) is a clinically successful method for relieving the most severe pain associated with rheumatoid arthritis or injuries to the knee joint and restoring physical function in patients.[2]

The knee, which sustains compressive forces up to six times body weight during normal life activities, transmits the weight of the body, inertia forces, and muscle forces to the ground.

This paper aims to steady the concepts and important terminology related to the knee joint. To study experimental stress analysis of prosthetic knee joint using a polariscope. To study the distribution of stresses in the same by assigning it, the desired material properties use FEA.

A. Prosthesis

In the field of medicine prosthesis is defined as an artificial device which is replaced in the position of any defective body part or when any part of body went missing because of trauma, disease or any congenital condition. Mainly two types of prosthesis are being used in i.e., craniofacial and somato (body). Craniofacial prosthesis is of two types i.e., extra oral prosthesis and intra prosthesis whereas somato prosthesis are of many types like limb prosthesis, ear prosthesis of any defective body parts when being replaced by an artificial organ [3].

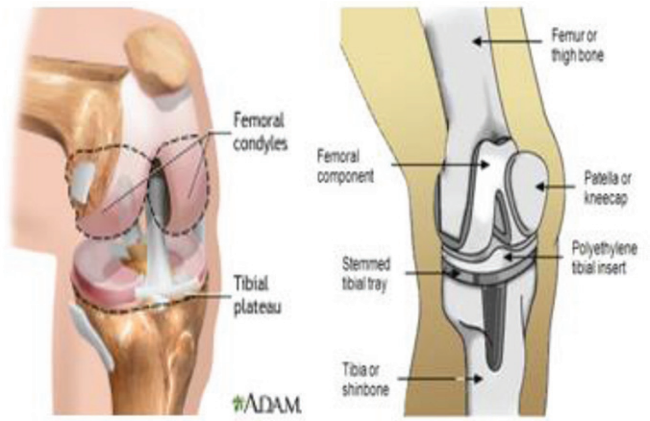

Figure 1: Normal knee joint and Artificial knee joint

B. Technique in Knee Replacement

Knee replacement is a surgical process that begins with a post-operative procedure and ends with a surgical operation an X-Ray of the load-bearing of the knee joint is performed for the knee replacement of both the lateral and AP of the knee with 30° flexion of the knee is performed to see the narrowing that has occurred in between the joints of the knee. To carry out the replacement and incorporate precise implants in that region, MRI is employed in conjunction with X-Ray imaging to see the effects of the cartilage and its problematic areas.

2.0 Procedure for Preparation of Photoelastic Model of Prosthetic Knee Joint

The mould chamber of the knee joint component is produced using epoxy resin with a thickness of 6mm plate during the fabrication of the knee model. A lower amount of hardener HY-951 added to CY-230 epoxy in preparations is allowed. In a 1:5 ratio, the hardener and epoxy are mixed together. Depending on the component size, these two are mixed. To manufacture larger castings, a greater hardener is necessary because the process is exothermic. Both elements are in a condition of liquidity. A fifty-minute mixture is needed. The hardener and resin mixture poured into the mold cavity of the knee joint component. The knee component takes 56 hours to solidify [4].

After solidifying the material photoelastic sheet is used to prepare a model of our requirement. The sheet is cut as per dimension with help of a wire cut machine.

Figure 2: Photoelastic models for 40mm radius and different angles

3.0 Material Properties

Nowadays, one of the challenging tasks for materials science is the development of new biomaterials for medical applications. Thus, there is an obvious need for better artificial implants. Furthermore, the formation of hierarchical structures is a remarkable feature of biomaterials. In addition, the complex functionality of the various tissues includes a continuous change from one structure or composition to another [5].

Table 2. Material Properties

Material Name	Epoxyresin	Notation	Unit
Trade Name	Araldite CY-230 with 10% hardener		
Poisson's ratio	0.38	υ	
Modulus of Elasticity	$2.62E^2$	E	MPa
Proportional limit	56	σ_{pl}	MPa
Stress Fringe value	11.59	$f\sigma$	

4.0 Experimental Study

Compressive Test of Tibia bone arrangements with investigation of Tibia bone obstruction in three upper, center and terminal parts as exploratory through compressive test and limited component strategy directed [6].

A. Photoelasticity: Photoelasticity is a technique that uses a whole-field approach to measure and visualize stresses and strains in materials. This method employs a birefringent model of the actual structure to show stress contours caused by external loading or residual birefringence. Because stress conditions are taken into account before production, photoelastic analysis can be performed during the design phase, where it displays the stress distribution around material discontinuities. This approach is typically used to evaluate two-dimensional stress systems. Maxwell's stress optic law is the basis for such work.

Stress optic law $(\sigma)=\frac{Nf\sigma}{h}$ N/mm^2

Where,

σ = Stress in the model, N = Number of fringes in material, fσ = Fringe value, h = Thickness of model

B. Polariscope: The polariscope is a piece of optical inspection equipment that is used to detect stress concentration in glass and other optical materials such as plastics and polyurethanes. A polariscope is made up of a light source and two crossed polarised lenses, similar to the ones seen in polaroids.

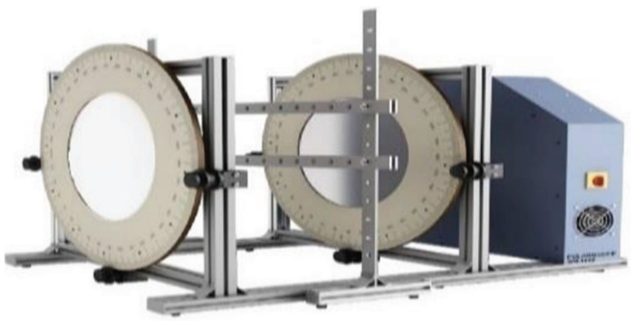

Figure 3: Polariscope Machine Setup

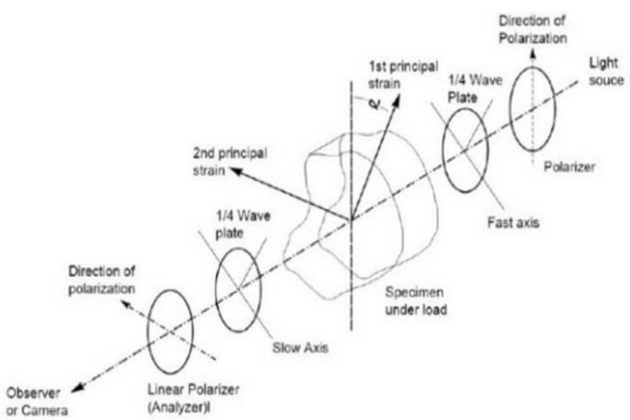

Figure 4: Schematic diagram of polariscope

C. Optical Arrangement in Polariscope Machine

Table 1. Optical arrangement in a polariscope

Machine set up	Polarizer and analyzer	Quarter wave plate	Background
Plane polariscope	Crossed	None	Dark
	Crossed	Crossed	Dark
Circular polariscope	Crossed	Crossed	Dark
	Parallel	Parallel	Dark
	Crossed	Parallel	Bright

D. Calculation of Stress

The equation for the stress optic law is as follows

$(\sigma_1 - \sigma_2) = \frac{Nf\sigma}{h}$ N/mm^2 ... (1)

where

σ_1 and σ_2 = Principal stresses at maximum and minimum levels in N/mm^2

fσ = Fringe value of material in N/mm.

N = Fringe order in the material.

Consider a model that is round (the knee model is assumed as half of the circle)

$f\sigma = \frac{8P}{\pi DN}\cos\alpha$ ... (2)

where

P = Applied force on the model in Newton

D = Diameter of the model in mm.

á = Flexion angle

h = thickness of the model in mm

For the photoelastic model 40mm radius and 15° flexion angle

P= 49.05 N, h= 6mm, N= 1, α= 15°, D= 80mm

$$f\sigma = \frac{8P}{\pi DN}\cos\alpha$$

$$f\sigma = \frac{8*49.05*10}{\pi*80*1}cos15$$

$$f\sigma = 15.08$$

now stress is calculated as,

$$\sigma = \frac{Nf\sigma}{h}$$

$$\sigma = \frac{1*15.08}{6} = \mathbf{2.51\ N/mm^2}$$

5.0 Finite Element Analysis (FEA) of Prosthetic Knee Joint

FEA is a simulation method. It is used to solve irregular, complex shape geometries. It is discretized whole body into a small number of parts and solving differential equation gives a result. In this method, we used Ansys analysis software for prosthetic knee joint analysis.

The 2D model of the femur and tibia was created in CATIA modeling software. The model is designed as per dimensions and our requirement. The dimension model of the knee joint with 40mm, 50mm sagittal radius and 150, 200, 250 flexion angles were taken while creating model [7]. After geometry is imported to analysis software. material property is given to the model. Then meshing model quad element or tetra mesh. Applying boundary condition to the model and solving mathematical model. Results are viewed in general postprocessor.

The results of 40mm radius 150 flexion angle is shown below

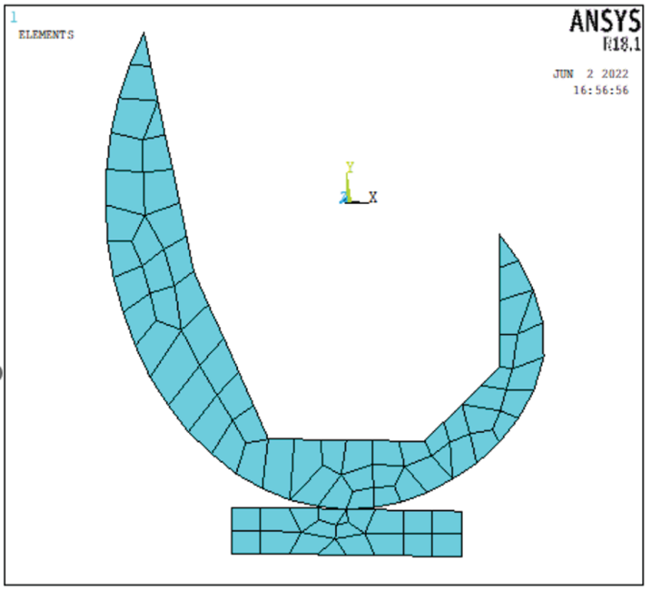

Figure 5: Meshing of model

6.0. Result and Conversation

A polariscope machine is used to conduct the experiment. Finding a stress distribution on the model of various loading conditions and Von mises stress is find out in the finite element analysis method.

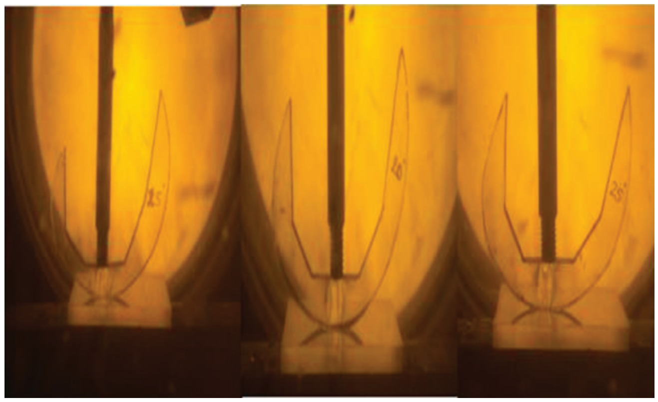

Figure 6: Stress distribution on photoelastic model for 40mm radius 150,200,250 flexion angles

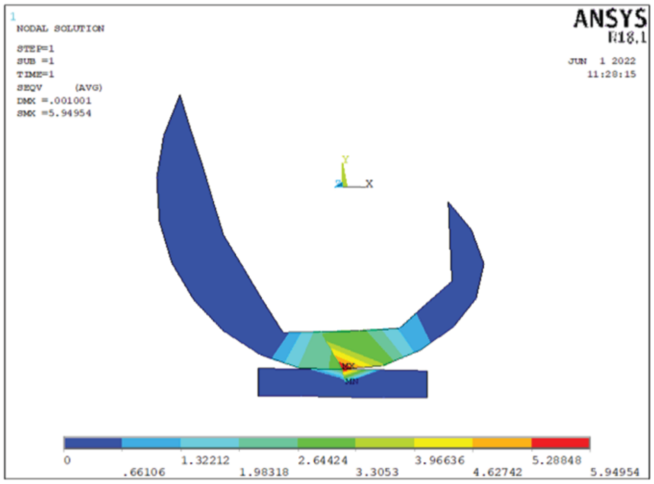

Figure 7: Von mises stress distribution for 40mm radius 150 flexion angle

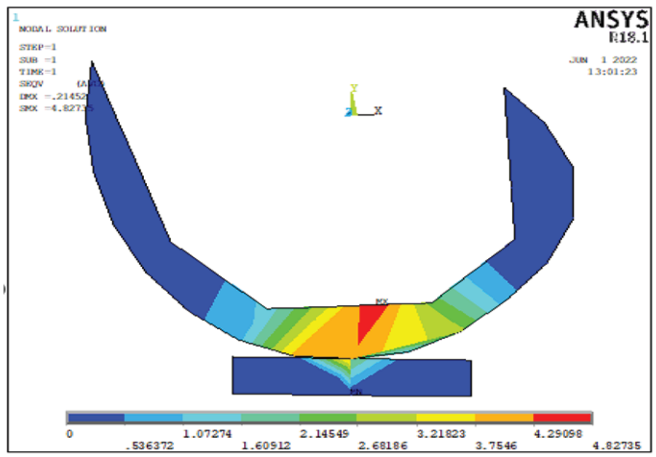

Figure 8: Von mises stress distribution for 40mm radius 200 flexion angle

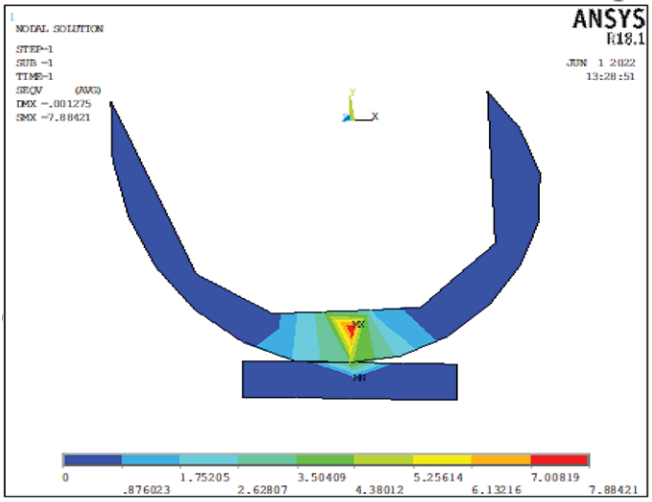

Figure 9: Von mises stress distribution for 40mm radius 250 flexion angle

The above figures show an experimental stress analysis. The load is gradually applied on the knee model for different flexion angles 150,200,250 as 5Kg, 10Kg, 15Kg, and 20Kg. [8] the compressive load is applied to the model gets stressed fringes are formed on the photoelastic model from the stress optic law equation using these fringes find out the stress inside the model.

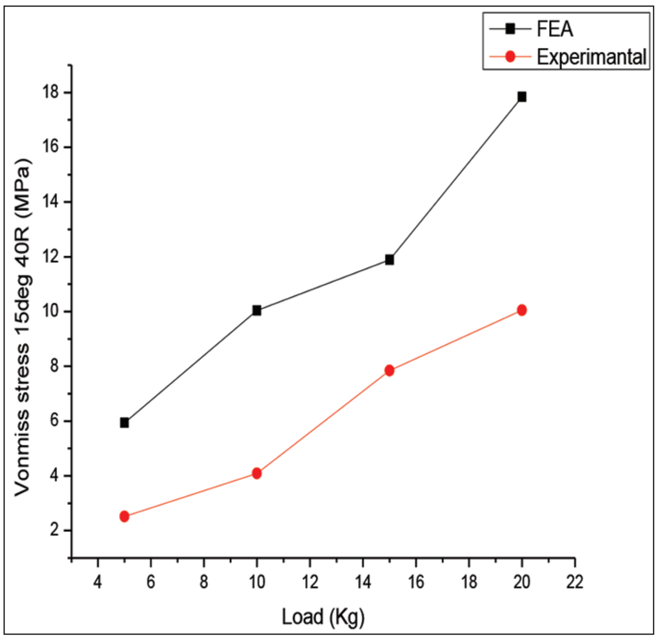

Figure 10: Von mises stress for different loads compares with Experimental V/S FEA results (15º Flexion angle and 40mm sagittal radius)

From FEA analysis the model is imported to the analysis software. Selecting 45 Brick element and giving material properties like young's modulus (E) = 2.62E3 MPa, poisons ratio (μ) = 0.38. then applying boundary conditions to the model, the analysis software solves the equation and gives the result.

The Figs.10 and 13 show a comparison between Von mises stress distribution to various loading

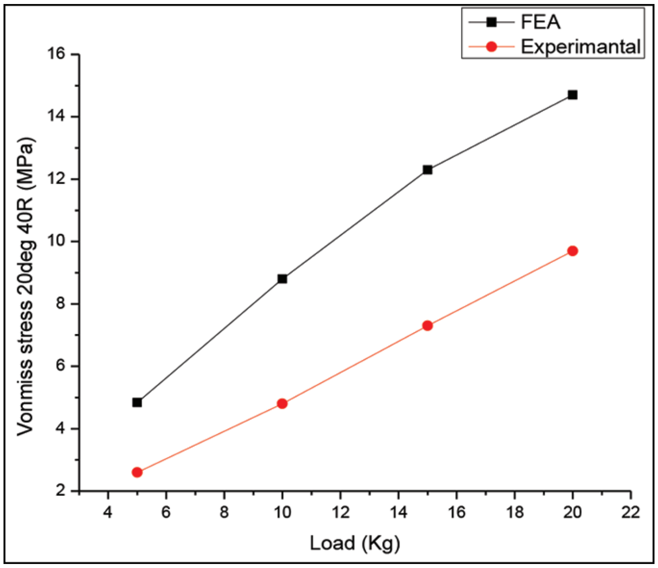

Figure 11: Von mises stress for different loads compares with Experimental V/S FEA results (20º Flexion angle and 40mm sagittal radius)

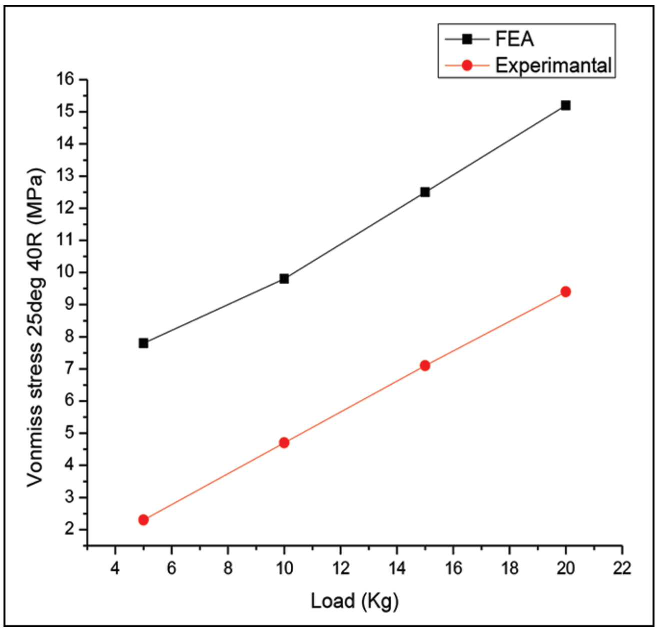

Figure 12: Von mises stress for different loads compares with Experimental V/S FEA results (25º Flexion angle and 40mm sagittal radius)

condition at 150 flexion angle. As load increases stress also increases. FEA stress is more than experimental stress for both 40mm and 50mm radii. Comparing Figs.10 and 13, 50mm radius model has to stress less

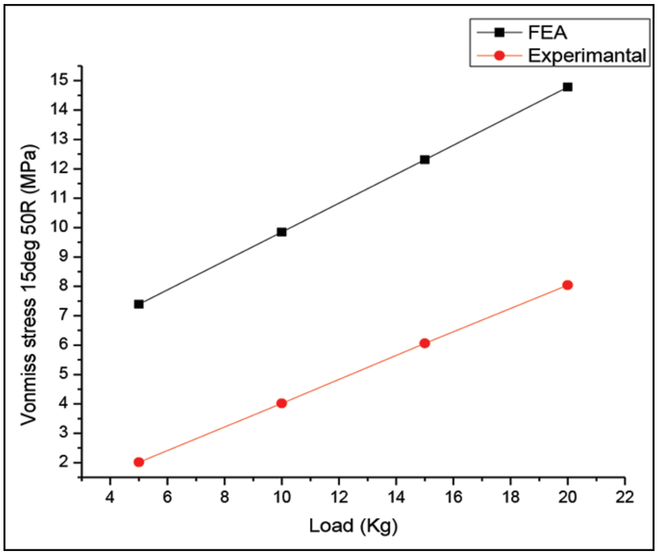

Figure 13: Von mises stress for different loads compares with Experimental V/S FEA results (15° Flexion angle and 50mm sagittal radius)

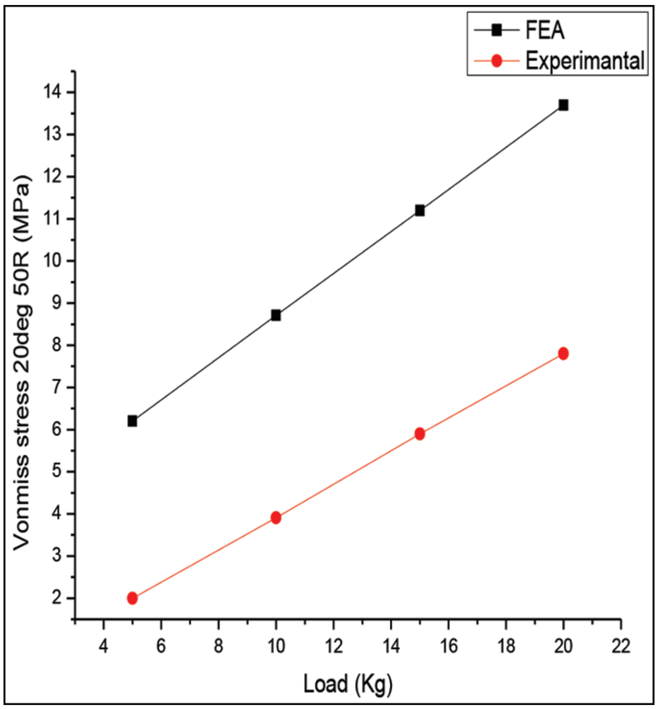

Figure 14: Von mises stress for different loads compares with Experimental V/S FEA results (20° Flexion angle and 50mm sagittal radius)

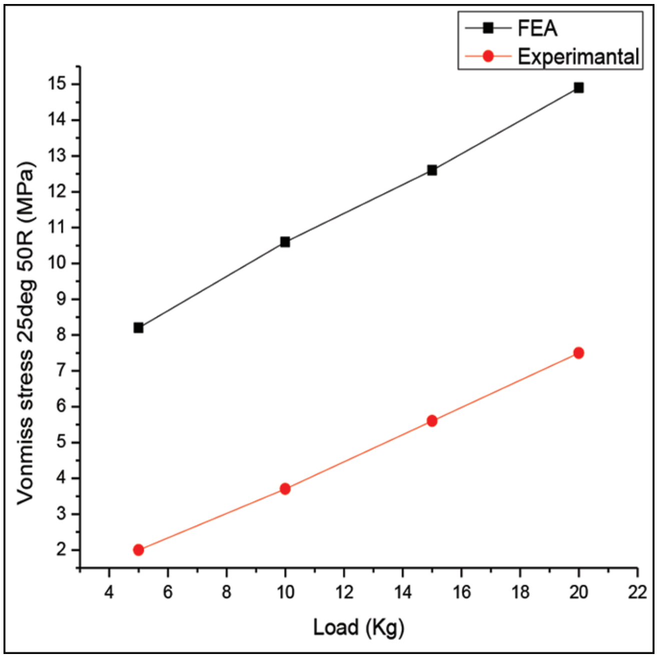

Figure 15: Von mises stress for different loads compares with Experimental V/S FEA results (25° Flexion angle and 50mm sagittal radius)

than the 40mm radius model. Figs.11 and 14 show stress vs load for 40mm and 50mm radius for 200 flexion angle. Comparing stress is more in the 40mm radius model as the angle increases stress is reduced.

Figs. 12 and 15 show Von mises' stress vs load for 40mm and 50mm radius. Comparing above mentioned figures stress is more in 40mm radius model because area is less in that model as compared to 50mm radius model.

7.0 Conclusion

Finally, we conclude that the difference between the experimental and finite element analysis (FEA) values are satisfactory. In this study, the distribution of stress in a photo elastic model and how it acts in different sagittal radius and flexion angles are investigated. One more observation is stress increases with increasing a load on the model.

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