DESIGN, MODELING AND OPTIMIZATION OF A "PROSTHETIC RUNNER BLADE

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Abstract

Design of a blade runner is important for Biomedical Engineering which involves the science of Mechanical Engineering applications to obtain best results. In general it is an application for the leg amputated (trans-tibial) individuals to replace their below-knee part with a runner blade. It is designed to mimic the action of the anatomical foot/ankle joint of able-bodied runners and help compensate for the user's impaired physiology. However, certain case studies must be made based upon the journals that include motion studies on ankle and foot.

In this project the 3D model is designed in modeling software such as Solidworks/CATIA V5. Then the design is converted into Finite Element Model and the meshing is done correspondingly. After meshing, the model is imported to Solver (ANSYS V14) to perform analysis. Hence, the required results of the stress concentration and deformation values are obtained. Finally, based upon these values the design is re-modified to its optimum efficiency.

Keywords: Blade runner, finite element meshing, fiber reinforced composites

I. INTRODUCTION

A runner blade design involves the high engineering applications which include Finite Element Analysis and Simulation with various analysis techniques for its better optimization. The computer revolution, which is sweeping the globe, brings inexorable changes to all companies. Computer simulation of this process is becoming an indispensable tool in the industries.

OBJECTIVES

- To do a case study of the composite materials that satisfies all the requirements for designing a prosthetic runner blade.
- To design and optimize a prosthetic runner blade based on its strength calculated from analytical results.
- To reduce the manufacturing cost of a prosthetic runner blade.

II. SURVEY ON BLADE RUNNERS

In India, there are 424,000 amputees where 23,500 amputees are added to the amputee population in India every year, of which 20,200 are males and 3,300 are females. In July 1999 revived by an anaesthetist, Major DP Singh having lost a leg to shrapnel injuries and gangrene went to the Artificial Limb Centre in Pune, where he found a replacement for his lost limb. Ten years later, Singh ran the 2009 Delhi Half Marathon — a distance of 21 km — in 3 hours and 49 minutes.

3. MATERIALS REQUIRED

- Fiber Reinforced Composite
- Fasteners
- 3D Design Software
- FEM Software

- Analysis Software
- Simulation Software

The cost of the project is completely based upon the FRC material and the software used.

Selection criteria

TABLE I.

Type of fibers	Tensile strength [GPa]	Young modulus [GPa]
High strength – HT	3.3 – 6.9	200 – 250
Intermediate modulus – IM	4.0 – 5.8	280 – 300
High-modulus – HM	3.8 – 4.5	350 – 600
Ultra-high-modulus – UHM	2.4 – 3.8	600 – 960

From the above table, we chose High strength (HT) type of carbon FIBER as per the strength requirement.

TABLE II

Different types of carbon Fibers and their properties

Fiber Type	Number of Filaments	Tensile Strength		Tensile Modulus*		Strain**	Weight/Length	Density	Standard Spool Size
		ksi	MPa	Msi	GPa	%	(g/m)	(g/cm³)	(lb)
AS2C	3,000	639	4,406	32.7	225	1.9	0.200	1.80	4.0
AS4	3,000	668	4,606	33.5	231	1.8	0.210	1.79	4.0
	6,000	643	4,433	33.3	230	1.8	0.427	1.79	4.0
	12,000	653	4,502	33.8	233	1.8	0.858	1.79	8.0
AS4C	3,000	669	4,613	33.5	231	1.8	0.200	1.78	4.0
	6,000	634	4,371	33.1	228	1.8	0.400	1.78	4.0
	12,000	652	4,495	33.6	232	1.8	0.800	1.78	8.0
AS4D	12,000	684	4,716	35.1	242	1.8	0.765	1.79	8.0
AS7	12,000	702	4,840	35.8	247	1.8	0.800	1.79	8.0
IM2A	6,000	740	5,102	40.0	276	1.7	0.223	1.78	2.0
	12,000	790	5,447	40.0	276	1.8	0.446	1.78	4.0
IM2C	12,000	800	5,516	43.0	296	1.9	0.446	1.78	4.0
IM6	12,000	830	5,723	40.8	281	1.9	0.446	1.76	8.0
IM7	6,000	773	5,330	40.2	277	1.8	0.223	1.78	2.0
	12,000	824	5,681	40.3	278	1.9	0.446	1.78	4.0
IM8	12,000	885	6,102	44.4	306	1.8	0.446	1.78	4.0
IM9	12,000	890	6,136	44.0	303	1.9	0.335	1.80	2.0
IM10	12,000	1,010	6,964	44.0	303	2.1	0.324	1.79	2.0

TABLE III

Types of carbon FIBER manufacturing companies worldwide

PRODUCER	BRAND NAME	2008	2010	2012
Toray Group	Torayca	17,900	20,900	21,250
Toho Tenax Co. Ltd.	Tenax	11,800	13,500	15,800
Mitsubishi Rayon Co. Ltd	Pyrofil, Grafil	8,100	10,100	13,314
Formosa Plastics Group	Tairyfil	6,150	8,750	11,431
Hexcel	**HexTow**	**5,900**	**15,800**	**22,569**
Cytec Engineered Materials	Thornel	2,000	3,000	7,332
Aksa Turkey	Aksaca	0	1,500	2,985

Finally, depending upon the strength to weight ratio, availability and cost, Hexcel's Hex Tow AS 4 Carbon Fiber is selected as a material for the prosthetic runner blade.

TABLE IV

Properties of Hex Tow AS 4 Carbon Fiber

Properties of Outline Row 3: carbon fiber

	A	B	C
1	Property	Value	Unit
2	Density	1740	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	2.15E-06	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Mo...	
8	Young's Modulus	2.31E+05	MPa
9	Poisson's Ratio	0.1	
10	Bulk Modulus	9.625E+10	Pa
11	Shear Modulus	1.05E+11	Pa
12	Tensile Yield Strength	800	MPa
13	Tensile Ultimate Strength	4400	MPa
14	Compressive Ultimate Strength	1540	MPa

4.3D Model (Initially designed in CATIA V5)

After a survey of blade runners, a design was made optimizing its length by considering the average height of a human being.

5. DESIGN SPECIFICATIONS

COMPONENTS	PARAMETERS	DIMENSIONS (mm)
	• Length	400 mm
RUNNER	• Width	60 mm
	• Thickness	10 mm
	• Width	5 mm
HOLDER	• Length	220 mm

Sketch dimensions

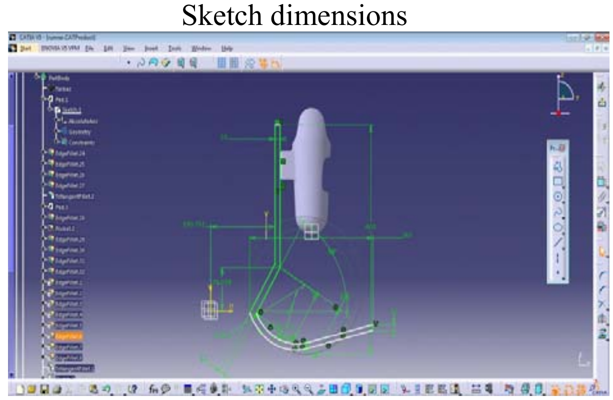
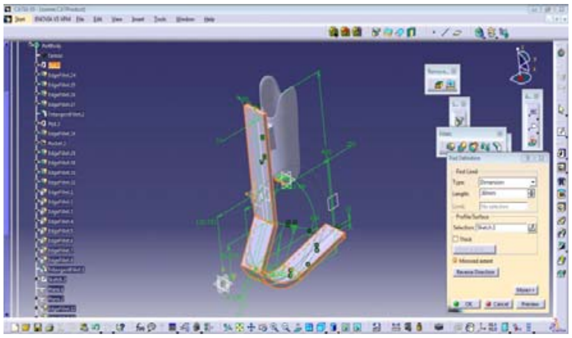


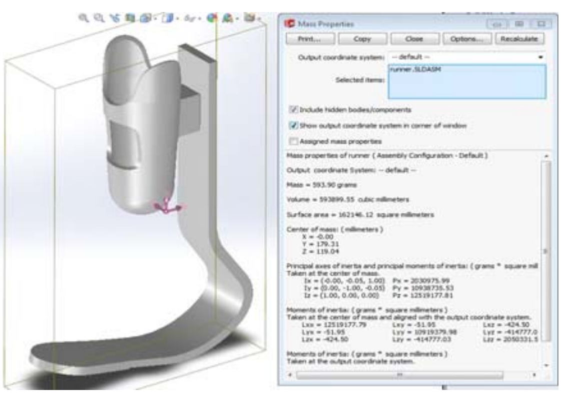
Fig Runner Blade



Mass Properties

	VALUES
• Mass (kg)	0.593
2. Volume (mm³)	593899.55
3. Surface area (mm²)	162146.12
4. Centre of Gravity (mm)	Along X-axis - -0.00
	Along Y-axis - 179.31
	Along Z- axis- 119.04

Fig Mass properties defined in Solidworks



5 .DESIGN METHODOLOGY

- Sketching a prosthetic runner blade on paper (free hand sketch).
- 2d & 3d modeling in Solidworks.
- Converting it into a finite element model.
- Analysis of the model in ANSYS solver.
- Noting down the analytical results.
- Design modifications made based upon the results.
- analysis of the final model
- obtaining the final result

EARLIER CONSIDERATIONS

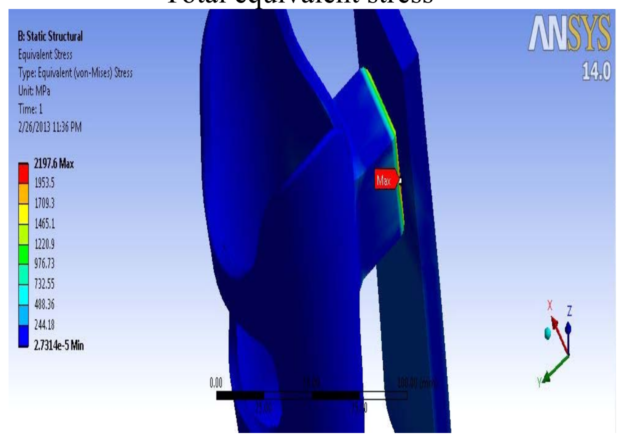
Mesh refinements

In the initial stages of analysis, a coarse mesh was applied in considering various parameters to obtain the stress and deformation values during one of the tests. During the process, it was found that the results obtained were not perfect.

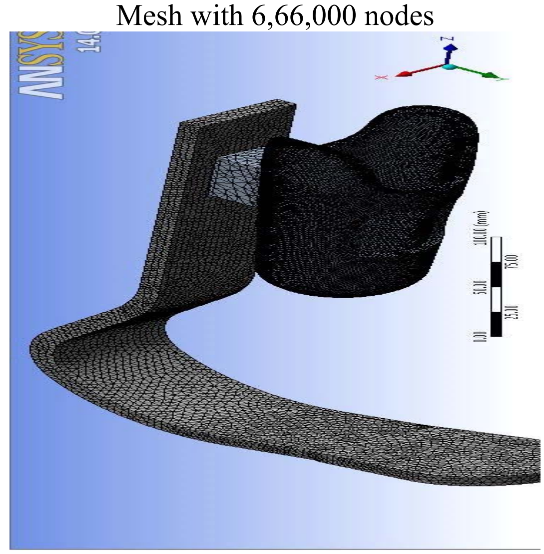
Hence, mesh refinement is done by increasing the number of nodes considering meshing parameters. Therefore, better results were obtained where the nodes increased from 6000 to 11,000.

To obtain much better results, it is more refined by increasing nodes from 11,000 to 6, 66,000. The results were satisfactory.

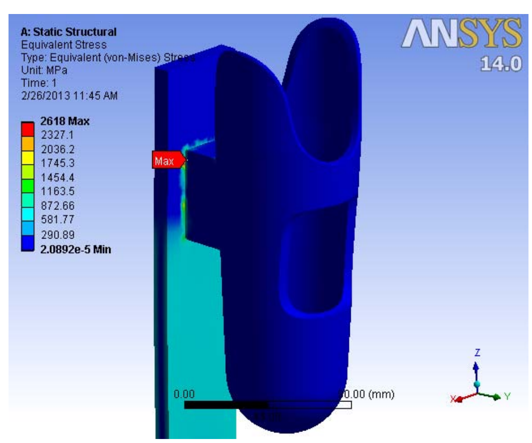
Total equivalent stress



Mesh with 6,66,000 nodes



Total equivalent stresses



TYPES OF ANALYSIS:

CASE CONSIDERATIONS: All the below analyses were done based on three cases.

- While running:

Considering one year life span for the prosthetic rune blade,

In a week, an average person runs 48 kilometers on foot, where he travels 2496 kilometers a year.

Assuming the distance covered by a person while running in a step is 1.25 m. Number of steps (n) required to cover the distance of 2496000 meters are (2496000/1.25)

N = 19968000,

Now, the force applied on the prosthetic rune blade must be determined.

We have,

F = m*a

Where,

F – Force acting on the prosthetic runner blade,

m- Mass of the prosthetic runner blade,

Acceleration due to gravity.

a = 9.8 m/ sec^2,

Now,

Assuming the average weight of the person to be 60 kg,

m = 60 kg,

F = 60 * 9.8 N,

F = 588 N,

The above applied force is acted upon feet.

Considering force acting on a foot,

F = 588/2=294N,

F = 300 N (Approx.)

STRESS CALCULATIONS

Per step

σ = (F/A),

Where,

σ – Stress under vertical loading,

F – Force applied,

A – Area subjected to the vertical force,

σ = (300/0.021),

σ = 142857.14 Pa,

σ = 0.142 MPa.

Note: Cyclic loading is applied in this condition; stress variants will be critically compared to other conditions.

- While jumping

Considering one year life span for the prosthetic runner blade,

In a week, an average person walks 25 kilometers which makes him to travel 1300 Kilometers in a year.

Assuming the distance covered by a person while walking in a step is 1 m.

Numbers of steps (n_1) required for the normal person to cover the distance of 1300000 m

Are,

n_1 = 1300000 steps,

And for a single leg amputee it takes 910000 steps to cover the distance with his runner

Blade,

N = n_1/2,

N = 650000 steps,

Now, the force applied on the prosthetic runner blade must be determined.

We have,

F = m*a,

Where,

F – Force acting on the prosthetic runner blade,

m- Mass of the prosthetic runner blade,

a - Acceleration due to gravity,

Now,

Assuming the average weight of the person to be 60 kg,

m = 60 kg,

F = 60*9.8 N,

F = 588 N,

The above applied force is acted upon feet.

Considering force acting on a foot,

F = 588/2,

F = 300 N,

STRESS CALCULATIONS

Per step

σ = (F/A),

Where,

σ – Stress under vertical loading,

F – Force applied,

A – Area subjected to the vertical force,

σ = (294/0.0015),

σ = 196000 Pa,

σ = 0.196 MPa.

The different types of analysis are performed:

- ROLL OVER ANALYSIS
- DROP TEST

ROLL OVER ANALYSIS

- Defining material

As the selected material is Hex Tow AS 4 Carbon FIBER, its properties were defined in the engineering data interface in ANSYS workbench.

- Applying mesh parameters

A suitable mesh is created considering various parameters as presented at the end of the report.

- Defining fixtures

The bottom part of the prosthetic runner blade is fixed as shown in the figure below

- Defining loads

A moment is applied to the holder of runner blade to determine the stresses caused due to rollover.

Here, a moment considering 3g load is applied to the runner blade as the extreme condition for rollover.

3g loading
F=3* (m*a),
F=70*9. 8*3,
F= 2058 N
Moment= F* perpendicular distance (d)
As d=400mm
Moment (M) = 2058*400
M= 823200 N-mm

- Evaluating results

Hence the required results are evaluated by calculating the input for rollover

- Plotting results

The results obtained are displayed below

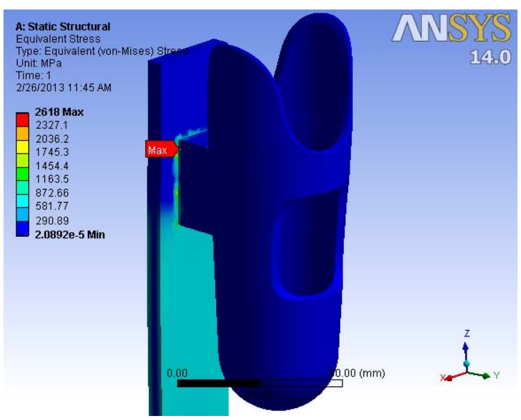


Fig 1. Closer view of total equivalent stress

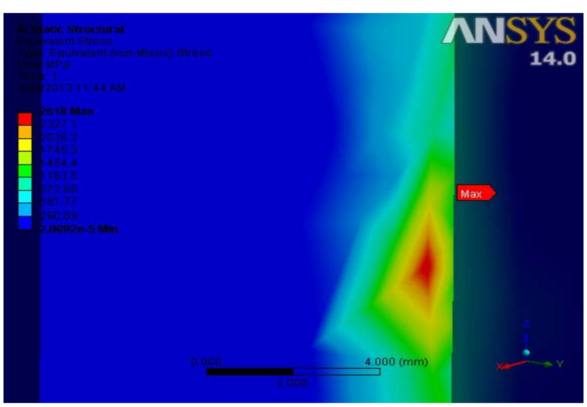
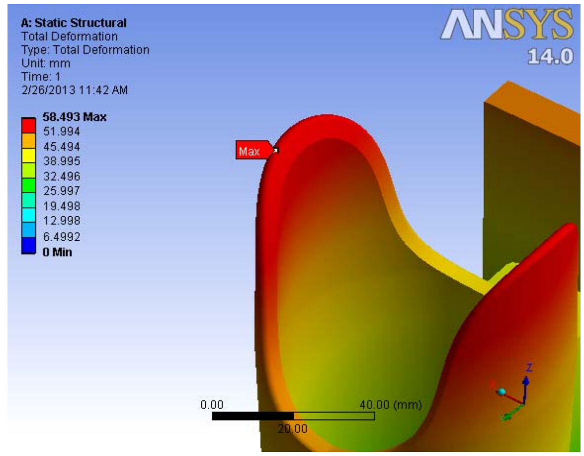


Fig 2. Total deformation



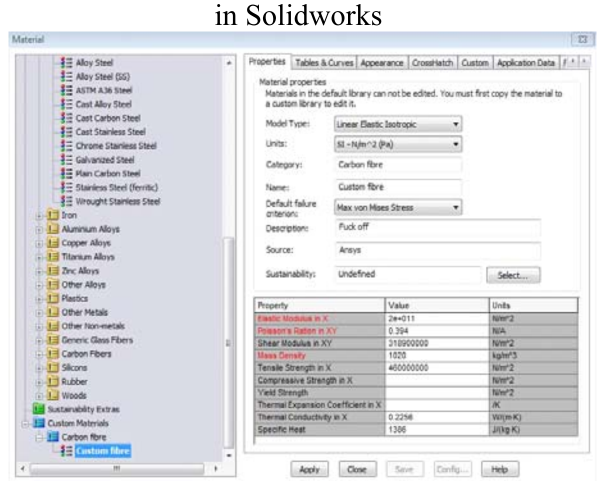
DROP TEST

In this test, two conditions are considered where a prosthetic runner blade is dropped from various heights to observe the types of stresses developed on it.

- Case I
- Defining material

As the selected material is Hex Tow AS 4 Carbon FIBER, its properties were defined in material data interface in Solidworks 2012.

Fig Customized Carbon fiber material creation in Solidworks



- Applying mesh parameters

A suitable mesh is created considering various parameters as presented at the end of the report.

- Defining fixtures

Here, the ground is fixed as a base upon which the runner blade is dropped

- Defining height

A height of 5 meters is chosen, from which the runner blade is made to drop down.

- Defining acceleration

As it is a freely falling body, acceleration of 9.8 m/s^2 is applied to the bottom part of runner blade as shown in the figure below.

- Defining result parameters

Here, a considerable amount of time is taken to perform the analysis.

t=35 Sec (assumption). Hence, suitable plots are derived.

Figures

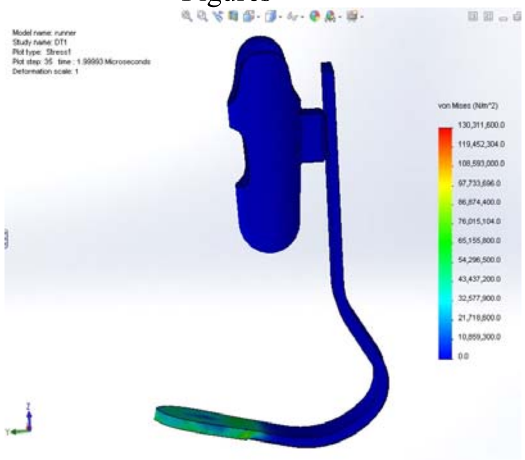
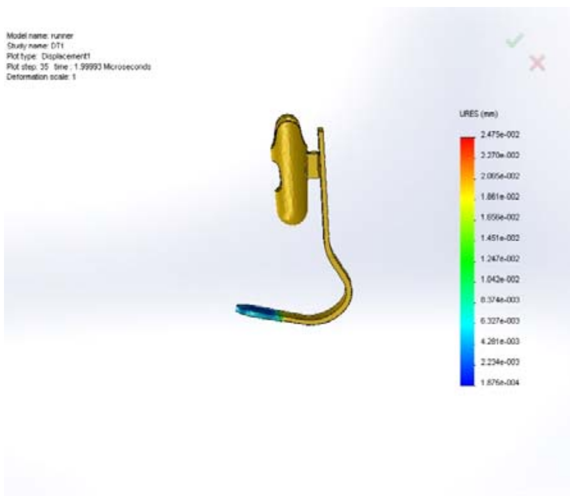


Fig . Total equivalent stress



Finite element model

Case II

- Defining material

  As the selected material is Hex Tow AS 4 Carbon FIBER, its properties were defined in material data interface in Solidworks 2012.

- Applying mesh parameters

A suitable mesh is created considering various parameters as presented at the end of the report.

- Defining fixtures

Here, the ground is fixed as a base upon which the runner blade is dropped

- Defining height

A height of 10 meters is chosen, from which the runner blade is made to drop down.

- Defining acceleration

As it is a freely falling body, acceleration of 9.8 m/s^2 is applied to the bottom part of runner blade as shown in the figure below.

- Defining result parameters

Here, a considerable amount of time is taken to perform the analysis.

t=30 Sec (assumption). Hence, suitable plots are derived.

Figures

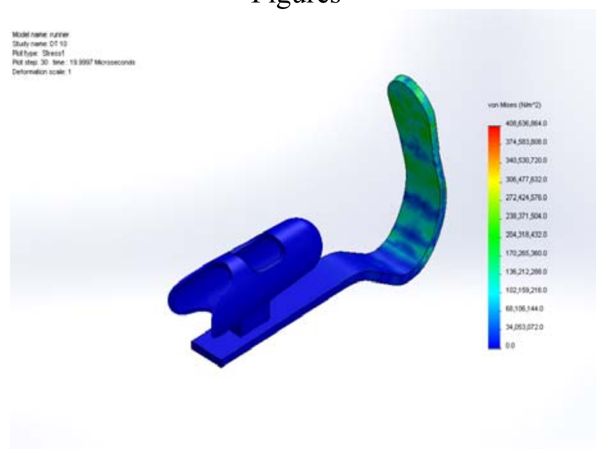


Fig . Total equivalent stress

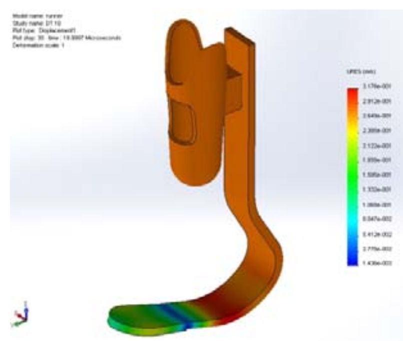
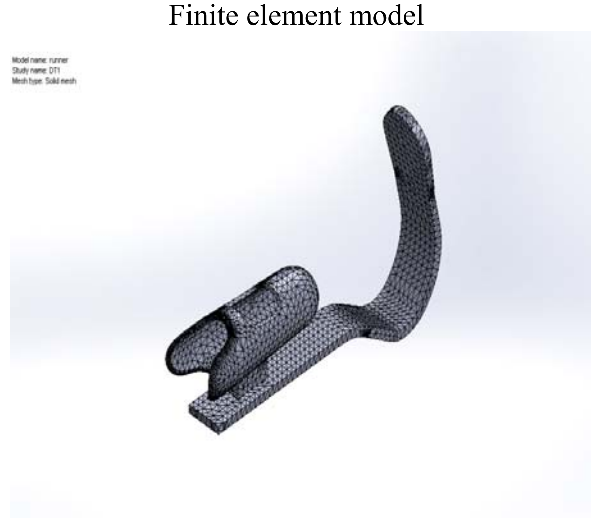


Fig . Total deformation

Finite element model



References

1. Judy Wagner,(L.P.T) , Susan Sienko(B.Sc.), Terry Supan, C.P.O,Daryl Barth(C.P.O), "Motion Analysis of SACH vs. Flex-Foot in Moderately Active Below-Knee Amputees".The American Academy of Orthotists and Prosthetists (November 1987), Vol.11, No.1, pp. 55-62.
2. Biswarup Neogi, Soumyajit Mukherjee, Soumya Ghosal, Sincham Ghosh, Achintya Das, "Simulation Techniques for Biologically Active Prosthetic Feet-An Overview". The International journal of Information Technology and Knowledge Management, January-June 2011, Vol 4, No.1, pp. 239-242
3. A.M. Boonstra, V. Fidler, G. M. A. Spits, P. Tuil, A.L.HOF, "comparison of gait using a Multiflex foot versus a Quantum foot in knee disarticulation amputees" .Prosthetics and Orthotics International. 1993,17, 90-94.
4. Tomohiro Yokozeki, Yukata Iwahori, Shin Ishiwata, Kiyoshi Enomoto, "Mechanical properties of CFRP laminates manufactured from unidirectional prepregs using CSCNT-dispersed epoxy". Science Direct-Composites: Part A 38 (2007) 2121-2130.
5. Jacquelin Pery, MD and Stewart Shanfield, MD, "Efficiency of Dynamic Elastic Response Prosthetic Feet". Journal of Rehabilitation Research and Development Vol. 30 No. 1, 1993, pages 137-143.
6. Dinesh Mohan, "A Report on Amputees in India." Orthotics and prosthetics, Vol.40, No.1, pp. 16-32.
7. J.K.W. Sandler, S. Pegel, M. Cadek, F. Gojny, M. Van Es, J. Lohmar, W.J. Blau, K. Schulte, A.H. Windle, M.S.P. Shaffer, "A comparative study of melt spun polyamide-12 FIBERs reinforced with carbon nanotubes and nanoFIBERs."Polymer 45 (2004) 2001-2015.
8. Ronald D. Snyder, MD; Christopher M. Powers, MS, PT; Catherine Fontaine , MPT; Jacquelin Perry, "The Effect of Five Prosthetic feet on the gait and loading of the sound limb in dysvascular below-knee amputees."Journal of Rehabilitation Research and Development Vol 32 No. 4, November 1995, pp 309-315.
9. Francois Prince, PhD; David A. Winter, PhD, PEng, Distinguished Professor Emeritus; Gary Sjonnensen, Bsc, Cp©; Corrie Powell, MSc; Robyn K. Wheeldon, Bsc, "Mechanical Efficiency during gait of adults with transtibial amputation: A pilot study comparing the SACH. Seattle, Golden-Ankle prosthetic feet." Journal of Rehabilitation Research and Development Vol. 35 No.2, June 1998 pages 177-185.
10. Carolin Curtze, At L. Hof, Helco G. van Keeken, Jan P.K. Halbertsma, Klass Postema, Bert Otten, "Comparitive rollover analysis of prosthetic feet." ELSEVIER- Journal of Biomechanics, 3 April 2009.
11. A.M Boonstra, V. Fidler, G.M.A. Spits, P. Tuil, A.L.HOF, "Comparison of gait using a Multiflex foot versus a Quantum foot in knee disarticulation amputees."Prosthetics and Orthotics International, 1993, 17, 90-94.