An Optimized Design and Modelling of Prosthetic Runner Blade

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Abstract— Design of a blade runner an integral part of Biomedical Engineering also engrosses the skill and art of Mechanical Engineering applications in order to have best possible effect. In general it is an application for the leg amputated (surgically removed) 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 bodily processes. This paper deals with the design, modeling and analysis of 3D model using Solid Works/CATIA V5 and extensive use of Finite Element Model through Solver (ANSYS V 14.0) to perform analysis. Further Stress concentration and deformation values are obtained and modified for the optimal efficiency.

Key words: Blade Runner, Fibre Reinforced Composites, Finite Element Model

I. Introduction

A. Runner Blade:

In medicine, a prosthesis "addition, application, attachment is an artificial device that replaces a missing body part, which may be lost through trauma, disease, or congenital conditions and Runner blade is prosthesis leg.

B. Runner Blade Design:

A runner blade design modeling and optitimization involves the high engineering applications includes Finite Element Analysis and Simulation tools. The computer revolution, which is sweeping the globe, brings inexorable changes leads to simulation of this process is becoming an indispensable tool in the engineering and industries.

C. Materials and Tools Requirement:

Fiber Reinforced Composite, Fasteners, 3D Design Software FEM Software, Analysis Software, Simulation Software. In this work depending upon the strength to weight ratio, availability and cost, Hexcel's HexTow AS 4 Carbon Fibre is selected as a material for the prosthetic runner blade.

Fig. 1: Runner Blade Positioning

Type	Tensile Strength (GPa)	Young Modulus
High Strength –HT	3.3 – 6.9	200 - 250
Intermediate	4.0 – 5.8	280 - 300
High Modulus –	3.8 – 4.5	350 - 600
Ultra High	2.4 – 3.8	600 – 960

Table 1: Types of fibers

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	669	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	279	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 2: Properties of fibers

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

Table 3: Properties of Hex Tow AS 4 Carbon Fiber

II. Methodology

In this paper to design and analyze the runner blade iteration based methodology was adopted discussed below:

- Sketching a prosthetic runner blade on paper (free hand sketch).
- 2d & 3d modeling in solid works.
- 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

Fig. 2: Initial Design of Blade Runner in CATIA V5

The above design based on a survey conducted for blade runner aesthetic, a design consideration was made by optimizing its length and is considered as the average height of a part below knee of human being.

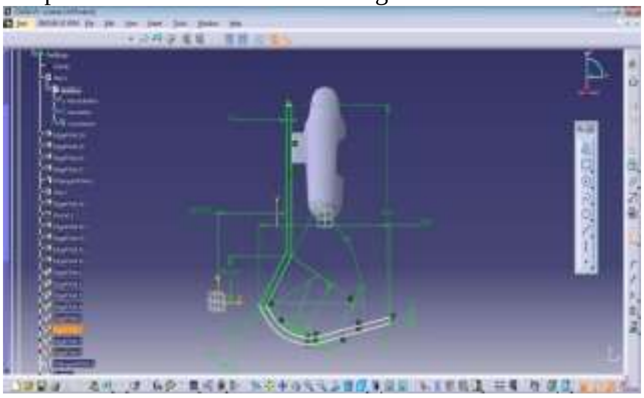

Fig. 3: DImensioned Blade Runner

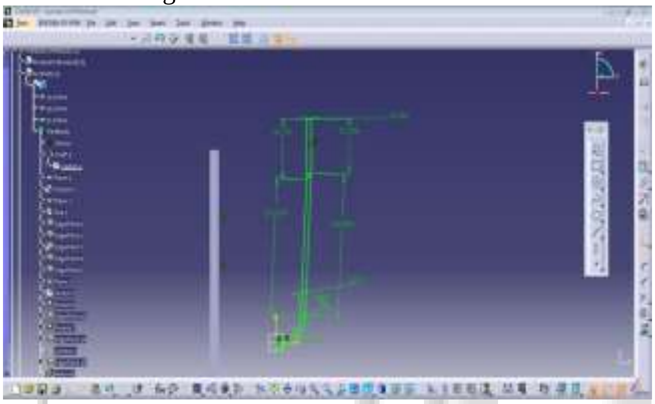

Fig. 4: Runner Blade

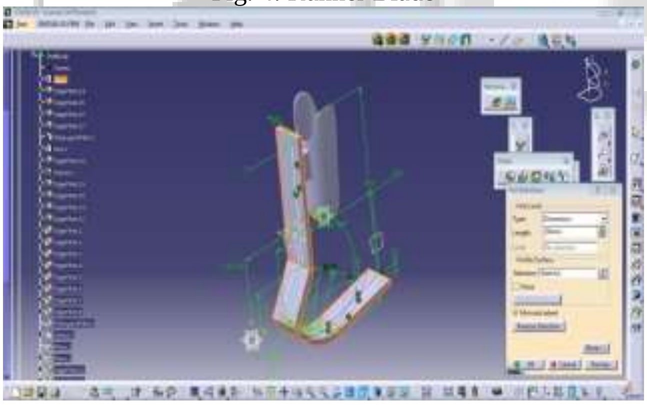

Fig. 5: Runner Blade Material Selecion

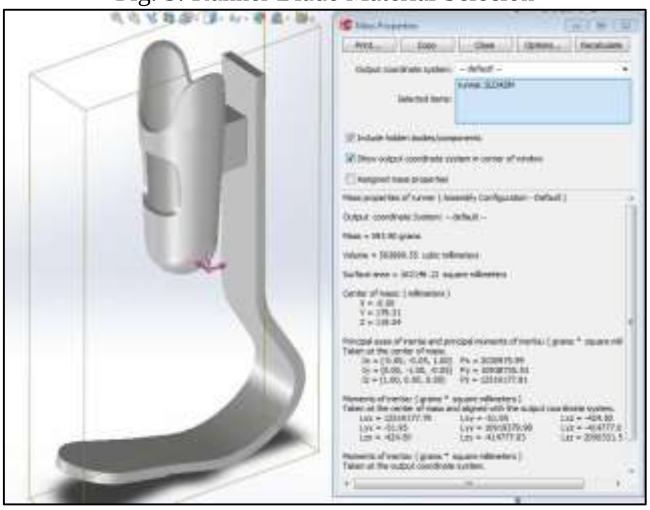

Fig. 6: Mass properties defined in Solid works

Various properties for the design of blade runner with the use of Hex Tow AS 4 carbon fiber for the outline row considered such as density, thermal expansion coefficient, Elasitcoty constants and strength values under tension and compression shown in table 3 and mass properties defined and taken for runner are shown in the figure above.

III. ANALYSIS

A. *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.

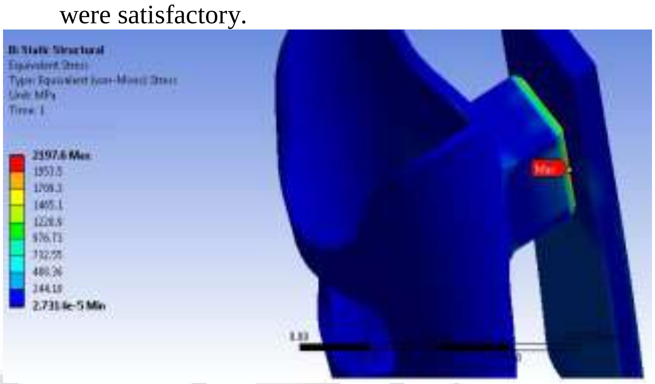

Fig. 7: Total equivalent stress: Mesh with 11,496 nodes

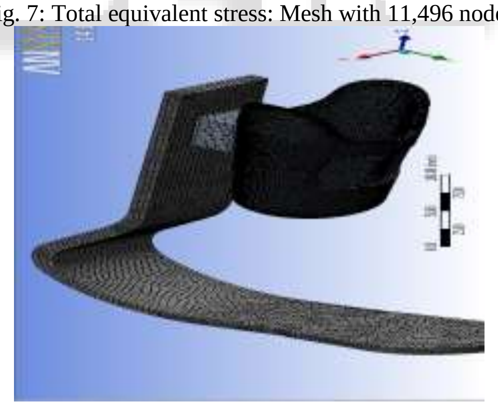

Fig. 8: Total equivalent stresses Mesh with 6,66,000 nodes

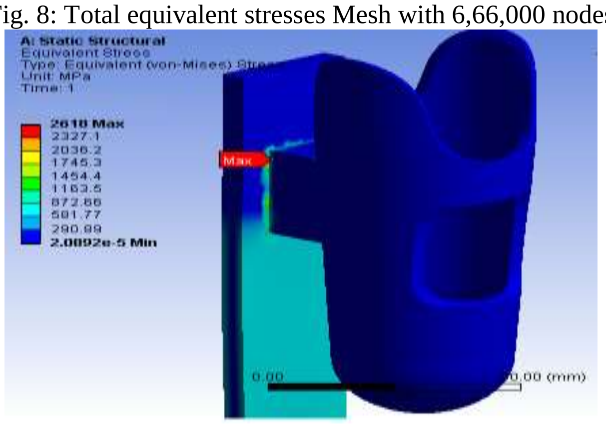

Fig. 9: Total equivalent stresses Mesh with 6,66,000 nodes

IV. RESULT AND CONCLUSION

In this paper to discuss the results of the performance of the blade runner against all the analyses done were based on two cases.

A. While Running:

It is design in such a way that it satisfies the consideration that one year life span for the prosthetic runner blade, with an assumption that in a week, on an average a person runs 48 kilometers on foot, where one travels 2496 km's 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,

Force applied on the prosthetic rune blade is determined by using the standard formula, F = m*a. where – Force acting on the prosthetic runner blade- Mass of the prosthetic runner blade, Acceleration due to gravity. a = 9.8 m/ sec^2, here in the paper it is assumed that the average weight of the person to be 60 kg, so it will give a force of F = 588 N, acted upon feet thereby force acting on a foot F = 294N.

Similarly while going for stress analysis for per step under the vertical loading on area subjected to vertical force σ = 0.142 MPa.

B. While Jumping

Instead of running 48 km per week here it is considered one year life span for the prosthetic runner blade, for a jumping of 25 KM in a week, on average person which makes total travel 1300 KM's in a year.

For an Assumption of 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, thus the force applied on the prosthetic runner blade will be F = 588 N acted upon feet and same for the foot294 N. Similarly while going for stress analysis for per step under the vertical loading on area subjected to vertical force σ = 0.142 MPa σ = 0.196 MPa.

C. Roll Over Analysis

Roll over analysis takes place by defining the material. Here as the selected material is Hex Tow AS4 Carbon fiber, its properties were defined in the engineering data interface in ANSYS workbench. There after by applying mesh parameters a suitable mesh is created considering various parameters. Then the position and fixture work takes place in which fixture is defined in terms of the bottom part of the prosthetic runner blade and is fixed as already shown in the figure 1. Once the fixture is defined 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 gives F= 2058 N and M= 823200 N-mm. With the results obtained the process of evaluation begins.

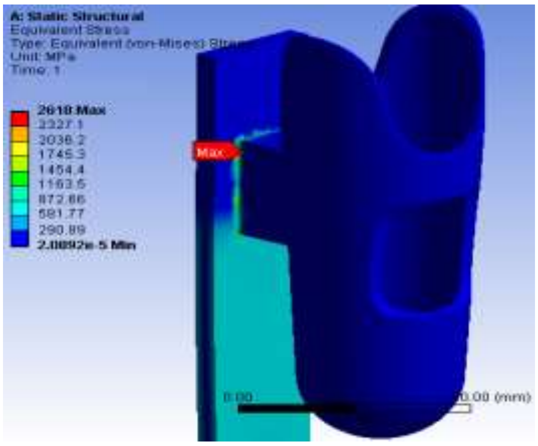

Fig. 10: Total equivalent stress

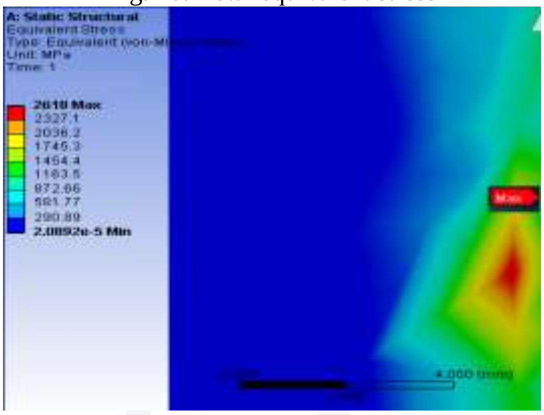

Fig. 11: Closer view of total equivalent stress

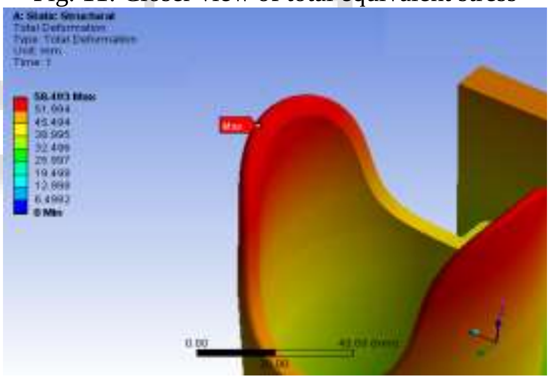

Fig. 12: Total deformation Finite element model

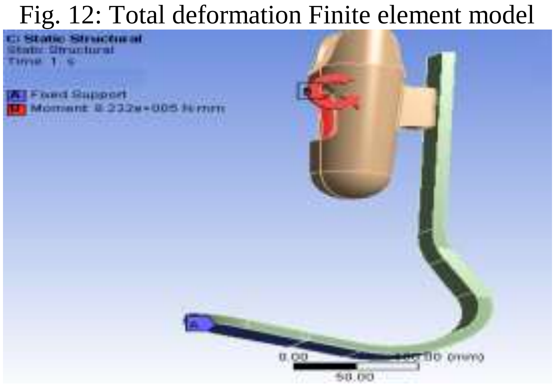

Fig. 13: After applying fixtures/ load

D. Drop Test Analysis

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.

In first case after deciding the material as "AS 4", suitable mesh is created considering various parameters.

Fixtures are defined, Here, the ground is fixed as a base upon which the runner blade is dropped.by defining height of 5 meters is chosen, from which the runner blade is made to drop down. Then acceleration is defined here it is a freely falling body, acceleration of 9.8 m/s^2 is applied to the bottom part of runner blade. Results parameters are defined. For a time t=35 Sec (assumption). Hence, suitable plots are derived.

Fig. 14: Finite Element Model

In second case again after deciding the material as "Hex Tow AS 4 Carbon fiber", suitable mesh is created considering various parameters. Fixtures are defined, Here, the ground is fixed as a base upon which the runner blade is dropped.by defining height of 10 meters is chosen, from which the runner blade is made to drop down. Then acceleration is defined here it is a freely falling body, acceleration of 9.8 m/s^2 is applied to the bottom part of runner blade. Results parameters are defined. For a time t=30 Sec (assumption). Hence, suitable plots are derived.

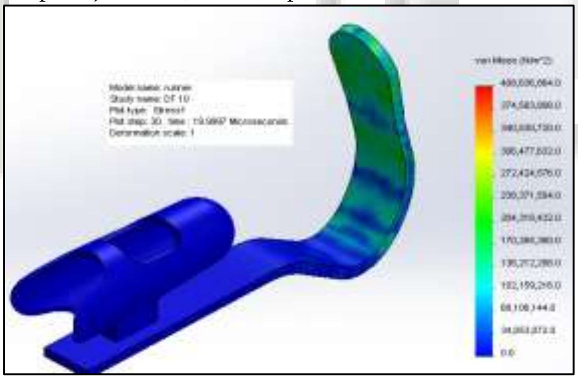

Fig. 15: Total equivalent stress

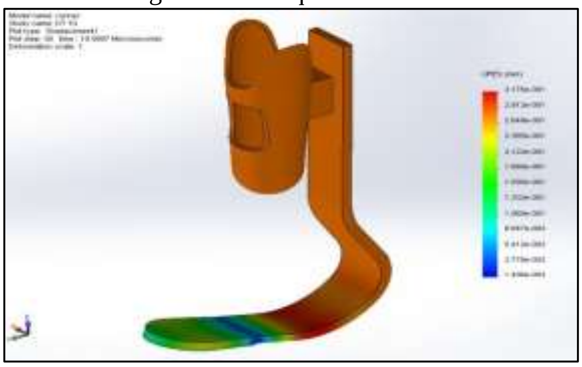

Fig. 16: Total deformation

References

[1] Judy Wagner Susan Sienko "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, "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, "comparison of gait using a Multiflex foot versus a Quantum foot in knee disarticulation amputees" .Prosthetics and Orthotics International. 1993, 17, 90-94.
[4] TomohiroYokozeki, Yukata Iwahori, "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, Stewart Shanfield, "Efficiency of Dynamic Elastic Response Prosthetic Feet". Journal of Rehabilitation Research and Development Vol. 30 No. 1, 1993, pages 137-143.
[6] Milan Motta, Shadab Imam, "Development of Assorted Solid Object Based on B-Spline" IJRAT, Vol 1, 2013, ISSN 2321–9637,
[7] Dinesh Mohan, "A Report on Amputees in India." Orthotics and prosthetics, Vol.40, No.1, pp. 16-32.
[8] J.K.W. Sandler, S. Pegel, M. Cadek, F. Gojny "A comparative study of melt spun polyamide-12 fibres reinforced with carbon nanotubes and nanofibres."Polymer 45 (2004) 2001-2015.
[9] Ronald D. Snyder, Christopher, "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.
[10] Milan Motta, "Modeling and Flexibility Analysis of Hydro Cracker Unit" Nov 2013 vol 3.
[11] Francois Prince, David A. Winter, "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.
[12] Carolin Curtze, G. van Keeken, "Comparitive rollover analysis of prosthetic feet." ELSEVIER- Journal of Biomechanics, 3 April 2009.
[13] A.M Boonstra, V. Fidler, "Comparison of gait using a Multiflex foot versus a Quantum foot in knee disarticulation amputees." Prosthetics and Orthotics International, 1993, 17, 90-94.