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Design and Analysis of Prosthetic Foot using Additive Manufacturing Technique

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ABSTRACT

Prosthetic feet are designed for an individual's foot at a particular activity level. Prosthetic foot is a style for people that cannot walk, the performance is basically cosmetic. For people who square measure most actively, a prosthetic foot should mimic a traditional foot throughout the act of walking. The fabric for prosthetic feet varies by varied use of foot and by varied application. Wood, plastic and foam are sometimes found in feet designed for people who have low activity levels and need stability. Carbon fiber feet meet the purposeful wants for shock absorption and energy potency, and square measure light-weight further. a variety of metals square measure used for prosthetic limbs; Al, Titanium, Magnesium, Copper, Steel, and lots of additional. titanium was discovered within the late eighteenth century. It's a typical metal used for medical and engineering applications due to its several favorable properties. it's sensible strength to weight quantitative relation, guck strength to density quantitative relation, glorious corrosion resistance, density and it's light-weight. So, perform static and model analysis on existing prosthetic foot to seek out stresses, total deformation. Then replace the fabric with the 3D printing additive producing technique. And find out the analysis result and compare the prevailing. Then experimental testing may be carried out to validate the result.

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KEYWORDS: *Design optimization, Prosthetic feet, 3 Point bending test, UTM*

I. INTRODUCTION

Over the past decade, technology and analysis have greatly enlarged the practicality and aesthetics of prosthetic feet. Today, amputees have a large array of feet from that to decide on. varied models square measure designed for activities starting from walking, performing arts and running to athletics, golfing, swimming and even snow sport. Heavier wood and steel materials are replaced over the years by light-weight plastics, metal alloys and carbon-fiber composites. Very like the vertebrate foot, several of today's prosthetic feet will store and come back a number of the energy generated throughout walking. different key attributes enclosed toe and heel springs that enable a lot of natural movement at the ankle joint, shock absorption, multi-axial rotation, adjustable heel heights, and waterproof materials.

Fig. Prosthetic foot

Prosthetic feet can be categorized into the following groups:

- Solid Ankle Cushioned Heel (SACH)
- Elastic (flexible) Keel Foot
- Single-Axis Foot
- Multi-Axis Foot
- Dynamic-Response Foot
- Microprocessor Foot.

The most basic prosthetic feet are available in 2 types: Solid ankle cushioned Heel (SACH) and Elastic Keel configurations. These styles contain crepe synthetic rubber or ester foam shaped over associate degree inner keel and formed to jibe a personality's foot. as a result of they need no hinged elements, these basic feet are comparatively cheap, sturdy and just about maintenance-free. These feet provide artifact and energy absorption however don't store and come with identical quantities of energy as dynamic-response feet. SACH and elastic keel feet are usually prescribed for amputees. The United Nations agency does a restricted quantity of walking with very little variation in speed.

SACH Foot: The SACH is the simplest form of non-articulated foot. The name refers to a somewhat soft rubber heel wedge that mimics articulation talocruralis action by pressing underneath load throughout the first part of the stance section of walking. The keel is rigid, and provides instance stability with very little lateral movement. The SACH foot is offered in varied heel heights to match individual shoes with completely different heel heights. Elastic (flexible) Keel Foot:

This prosthetic foot permits motion like that of SACH feet. additionally, the foot is in a position to adapt to uneven tract however remains adjunct and stable throughout standing and walking.

Fig. Concept of foot

II. LITERATURE REVIEW

Hongshen F. Britesa, C. Malçaa,, F. Gaspara, J. F. Hortaa, M. C. Francoa, S. Biscaiaa, A. Mateus. et.al[1], In this exploration work, plastic networks of HDPE – got from ordinary providers – were built up with various proportions of stopper waste and normal plug powders – acquired from stopper change enterprises – to track down the ideal combination for 3D printing. The impacts of plug powders content in the plastic on the morphological, physical and mechanical properties of the composites were researched through the thickness, optical microscopy, wettability, warm investigation and tractable testing. Stopper based composites were prepared by an expulsion framework, and the combination of polymer, glue and fillers is examined. The outcomes show that the expansion of unadulterated stopper and plug waste can be prepared with polymers like HDPE, having sufficient physical and mechanical properties. One of the motivations behind this work was to think about the impact of various plug powders blended in with a HDPE lattice. The outcomes taken from the stopper powders thickness estimations showed that plug squander thickness is higher than the unadulterated plug, prompting higher sum unadulterated plug in the composites combination than for the composites with plug squander. A higher level of plug waste can in this manner be added to the polymer framework.

Tiantian Li, Lifeng Wang, et.al[2], This paper centers around to consolidate 3D printing strategy, mathematical examination, and analyses to plan another class of sandwich composites that display different bowing practices. These customized sandwich structures contain 3D printed center materials with support, regular honeycomb, and re-contestant honeycomb geographies. Three-point twisting tests are performed to explore the bowing conduct of these sandwich composites with two kinds of carbon fiber built up polymer face sheets. Under bowing twisting, sandwich composites with bracket center materials give most elevated extramural solidness and strength that are alluring in primary segments. The sandwich composites with re-participant honeycomb center display a successive snap-through flimsiness which altogether improves the energy retention capacities. Our trial and mathematical outcomes demonstrate that architect ed center designs can be used to tailor the bowing properties just as disappointment systems. These discoveries offer new bits of knowledge into the investigation of nonlinear mechanical reaction of sandwich structures, which can profit a wide scope of businesses and applications.

Aman Sharma, Harish Garg. et.al[3], This paper is about the trend setting innovation of 3D printing, their execution in the individual fields and its critical commitment in the worldwide universe of science and clinical. In this paper we will manage the term Additive Manufacturing or 3D Printing and a smidgen of its set of experiences. Its different applications alongside the kind of materials utilized in the 3-D are likewise depicted. We will likewise illuminate the various chances given by this arising innovation just as the dangers and difficulties identified with it. Its ecological viewpoints are additionally displayed in the paper. Ultimately the degree and situation in future capability of 3D printing is additionally assessed.

Masaaki TSUTSUBUCHI, Tomoo HIROTA, Yasuhito NIWA, Tai SHIMASAKI. et.al[4], This paper traces the application patterns and investigation procedures followed by a clarification of the trademark physical properties of tars which might be the central issues for their functional application. Given the quick progression in PC execution, which has extended the size of calculation, the contribution of nitty gritty part data in regards to part arrangements has gotten moderately basic. The utilization of more nitty gritty models is additionally gradually becoming mainstream for material models which have considered disentanglement to be one of the consequences of more limited calculation time. Sumitomo Chemical likewise plans to join CAE for item plan with CAE for polymer plan later on.

Zhen Chen. et.al[5], According to this paper as of late 3D printing innovation is growing quickly. Soon, when 3D printing is generally utilized, the world's mechanical design will be incredibly changed. In light of the genuine information, this paper builds a worldwide store network model utilizing framework elements technique. What's more, it reproduces the recreation pattern of the inventory network after 3D printing application. The end shows that the widespread utilization of 3D printing will prompt the overall vehicle volume contracting drastically. The assembling exercises will continuously surge to the nations which are nearer to the last clients. The pertinent nations should do doable measures to confront this chance and challenge. The actions incorporate the change of coordinations offices, the coordinations participation with the beginning of 3D printing materials, and the coordinated with transportation of 3D printing materials and conventional handling ones.

N. Shahrubudin, T. C. Lee, * R. Ramlan. et.al[6], In this survey paper, there are rich scene of 3D imprinting in assembling industry. As of now, 3D printing innovation is starting in the assembling businesses, it offers numerous advantages to individuals, organization and government. Thusly, more data is expected to advance on approaches to upgrade the selection of 3D printing innovation. The more data about 3D printing innovation will help the organization and government to redesign and work on the framework of 3D printing innovation. Subsequently, this paper is to outline the kinds of 3D printing advances, materials utilized for 3D printing innovation in assembling industry and finally, the uses of 3D printing innovation. Later on, specialists can do some examination on the sort of 3D printing machines and the appropriate materials to be utilized by each kind of machine.

Vinod G. Gokhare, Dr. D. N. Raut, Dr. D. K. Shinde. et.al[7], This is an exploration paper on 3D printing and the different materials utilized in 3D printing and their properties which become an eminent subject in innovative viewpoints. In the first place, characterize what is implied by 3D printing and what is huge of 3D printing. They will go into the historical backdrop of 3D printing and learn about the cycle of 3D printing and what materials utilized in the assembling of 3D printed protests and select the best materials among them which are reasonable for our 3D printing machine. Likewise, see the upsides of 3D printing when contrasted with added substance producing.

Tianyun Yao, Zichen Deng, Kai Zhang, Shiman Li. et.al[8], In this paper to advance the mechanical examination and plan of 3D printing structures, a definitive rigidity of FDM PLA materials with various printing points were concentrated hypothetically and tentatively. A hypothetical model was initially settled to anticipate a definitive elasticity of FDM PLA materials dependent on cross over isotropic speculation, traditional cover hypothesis and Hill-Tsai anisotropic yield measure, and afterward checked by ductile trials. Contrasted and past models, this model gave two sorts of in-plane shear modulus estimation strategies, so the computation results were more dependable. The examples, planned by the current plastic-multipurpose test examples standard ISO 527-2-2012, were imprinted in seven distinct points with three layer thicknesses (0. 1 mm, 0. 2 mm, 0. 3 mm) for each point. The overall lingering amount of squares between hypothetical information and exploratory information were all near nothing, so the outcomes that the hypothetical model can precisely foresee a definitive elasticity of FDM materials for all points and thicknesses were affirmed.

Michael Dawoud, ImanTaha, Samy J. Ebeid. et.al[9], In this paper Carbon Black filled Acrylonitrile Butadiene Styrene (ABS) was utilized to set up a polymer composite by Fused Deposition Modeling (FDM) innovation. The impact of printing arrangement on the strain detecting conduct of the composite was examined, focusing on the creation of a fictionalized composite that can distinguish pressure or strain changes in designing individuals. Test work uncovered that inner anxieties can be identified dependent on observing the adjustment of obstruction as a reaction to strain. Estimations across test thickness were discovered to be generally reasonable for offering general expressions about the resistivity of the examples

Aubrey L. Woern, Joseph R. McCaslin, Adam M. Pringle, Joshua M. Pearce. et.al[10], This paper portrays the plan, manufacture and activity of a RepRapable Recyclebot, which alludes to the Recycle bot's capacity to give the fiber expected to generally repeat the parts for the Recyclebot on a RepRap 3-D printer. The gadget costs under $700 in mate rials and can be created in around 24 h. Fiber is delivered at 0. 4 kg/h utilizing 0. 24 kWh/kg with a distance across ±4. 6%. Hence, fiber can be made from business pellets for <22% of business fiber costs.

Edwin L. Thomas, and Mary C. Boyce. et.al[11], According to this paper two-part requested constructions wherein the two stages are strong and persistent (co-consistent strong designs) are un normal in nature and in business applications. Regular and manufactured co-consistent designs, involved hard and delicate materials can give remarkable mixes of properties including solidness, strength, sway obstruction, durability, and energy dispersal. The mathematical and topological plan of the constituents gives roads to design the macro scale properties. Different compound handling courses and advances currently empower the exact creation of requested co-ceaseless microstructure materials over a wide scope of length scales.

III. PROBLEM STATEMENT

Numerous prosthetic leg designs are available with various materials and functions. Although prosthetic foot is popular, the standard design is not established yet. This is due to the dedicated function. The cost of Existing foot is high and there are some cases that facing failure issue in prosthetic foot. Due to increased foot loss due to accident and increased foot amputation rate due to malignancy or gangrene, the demand for new prosthetic foot is also increasing. So we decide to varying material of prosthetic foot for improving performance.

IV. OBJECTIVES

- The main objective is to analyze the prosthetic foot structure and find out results.
- Using additive manufacturing technique to manufacture prosthetic foot.
- Study on 3D printing technologies
- Find out better material use for prosthetic foot using ANSYS software.
- Experimental validation of optimized prosthetic foot.

FEA OF PROSTHETIC FOOT

GEOMETRY

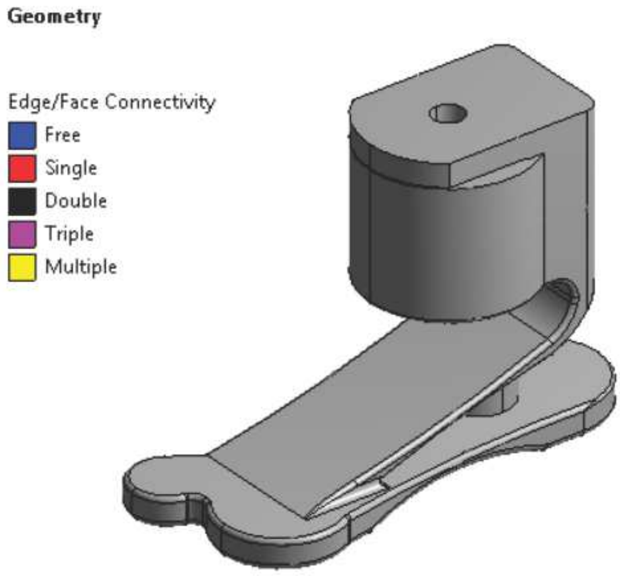


Fig. Geometry

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	950	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	0.00023	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Po...	
8	Young's Modulus	1100	MPa
9	Poisson's Ratio	0.42	
10	Bulk Modulus	2.2917E+09	Pa
11	Shear Modulus	3.8732E+08	Pa
12	Tensile Yield Strength	2.5E+07	Pa
13	Compressive Yield Strength	0	Pa
14	Tensile Ultimate Strength	3.3E+07	Pa
15	Compressive Ultimate Strength	0	Pa

Fig. Material properties of plastic

Properties of Outline Row 3: ABS

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	1.04	g cm^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus and Po...	
6	Young's Modulus	3500	MPa
7	Poisson's Ratio	0.35	
8	Bulk Modulus	3.8889E+09	Pa
9	Shear Modulus	1.2963E+09	Pa

Fig. Material properties of ABS

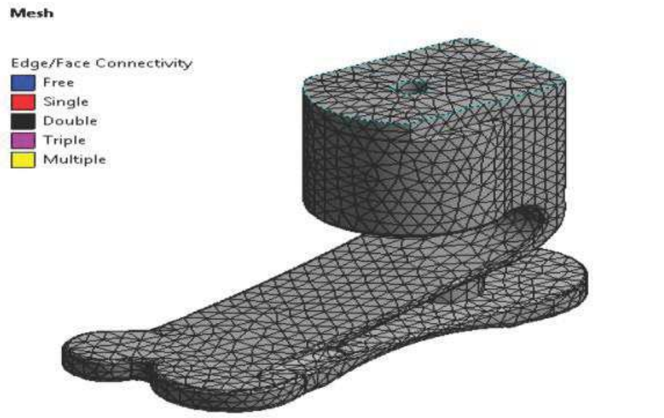
Properties of Outline Row 4: PLA

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	1.24	g cm^-3
4	Isotropic Elasticity		
5	Derive from	Young's Modulus and Po...	
6	Young's Modulus	2000	MPa
7	Poisson's Ratio	0.34	
8	Bulk Modulus	2.0833E+09	Pa
9	Shear Modulus	7.4627E+08	Pa

Fig. Material properties of PLA

Meshing

Meshing is an integral part of the computer-aided engineering simulation process. The mesh influences the accuracy, convergence and speed of the solution. Furthermore, the time it takes to create and mesh a model is often a significant portion of the time it takes to get results from a CAE solution. Therefore, the better and more automated the meshing tools, the better the solution.



Details of "Body Sizing" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size
Element Size	6.0 mm
Advanced	
Defeature Size	Default
Behavior	Soft

Statistics

Nodes	32309
Elements	19784

Fig. Meshing details

Boundary Condition

A boundary condition for the model is the setting of a known value for a displacement or an associated load. For a particular node you can set either the load or the displacement but not both.

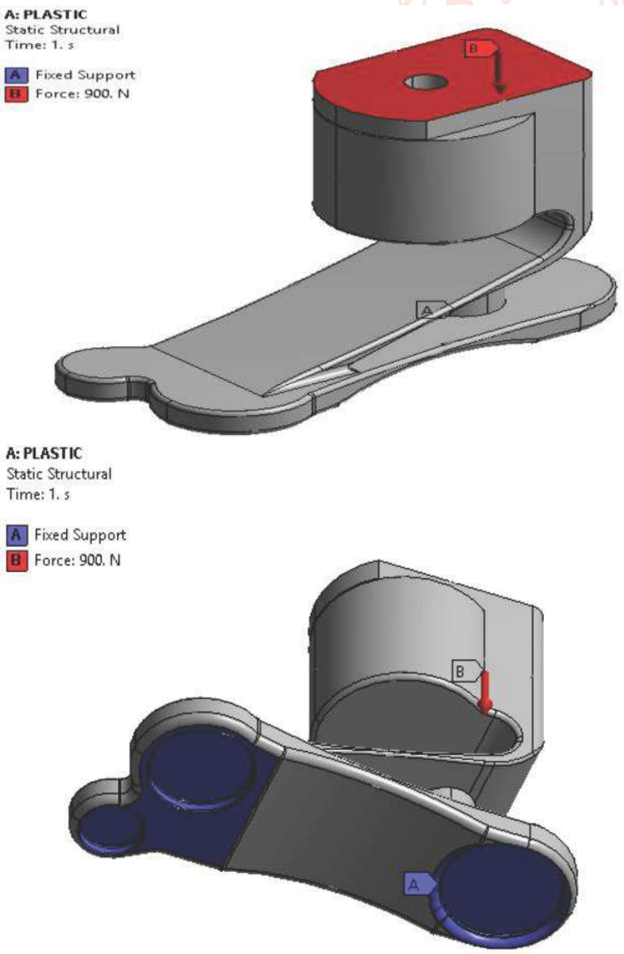


Fig. Boundary condition

The prosthetic foot we selected is use for child, age between 4 to 18. The maximum weight of child between this age is 75 kg.

By considering factor of safety 1. 2 the weight we applied on prosthetic foot is 90kg.
Force = 90 X 9. 81
= 900 N

RESULTS PLOT

Results for plastic material
Total deformation
The total deformation & directional deformation are general terms in finite element methods irrespective of software being used.

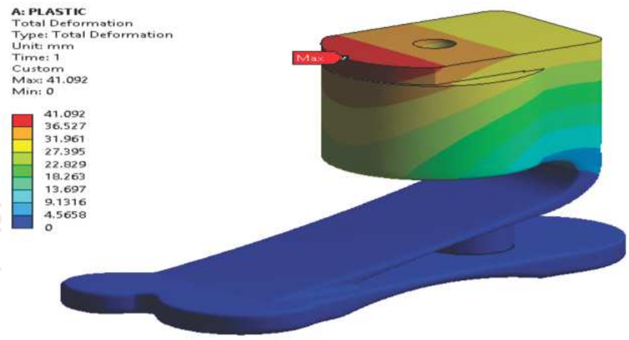


Fig. Total deformation

Equivalent Stress

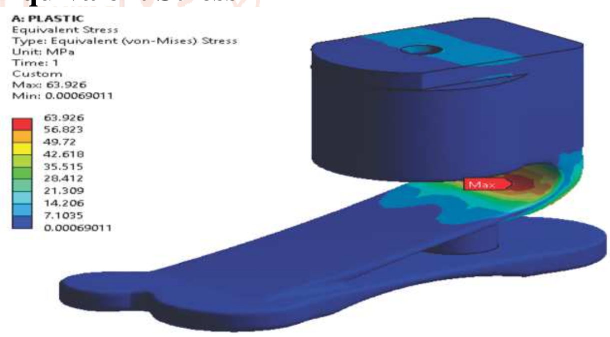


Fig. Equivalent stress

Results for ABS material
Total deformation

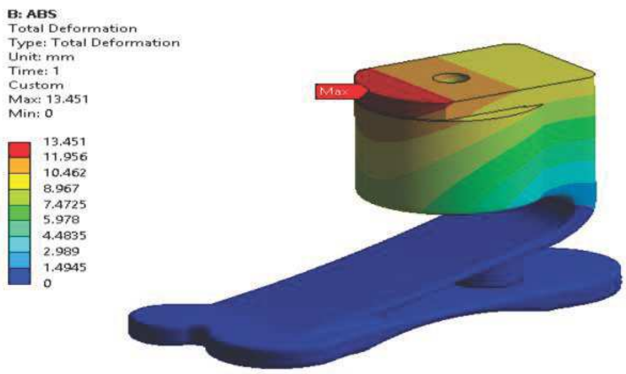


Fig. Total deformation for ABS material

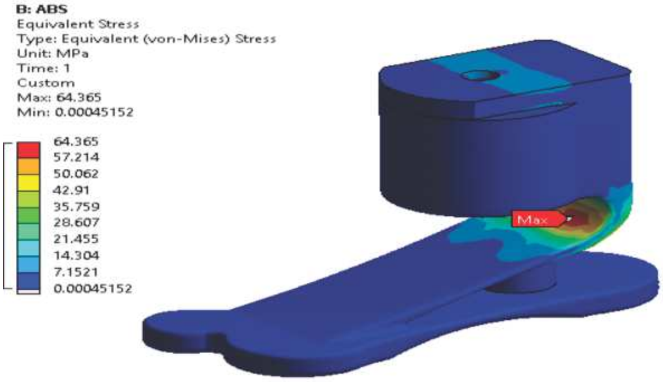


Fig. Equivalent stress for ABS material

Results for PLA material
Total deformation

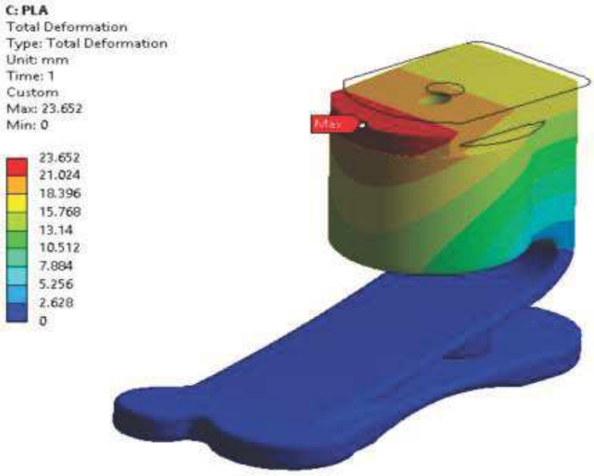


Fig. Total deformation for PLA material

Fig. Equivalent stress

EXPERIMENTAL VALIDATION:
A Universal Testing Machine (UTM) is used to test both the tensile and compressive strength of materials. Universal Testing Machines are named as such because they can perform many different varieties of tests on an equally diverse range of materials, components, and structures.

Universal Testing Machines can accommodate many kinds of materials, ranging from hard samples, such as metals and concrete, to flexible samples, such as rubber and textiles. This diversity makes the Universal Testing Machine equally applicable to virtually any manufacturing industry.

The UTM is a versatile and valuable piece of testing equipment that can evaluate materials properties such as tensile strength, elasticity, compression, yield strength, elastic and plastic deformation, bend compression, and strain hardening. Different models of Universal Testing Machines have different load capacities, some as low as 5kN and others as high as 2, 000kN.

SPECIFICATION OF UTM

1	Max Capacity	400KN
2	Measuring range	0-400KN
3	Least Count	0.04KN
4	Clearance for Tensile Test	50-700 mm
5	Clearance for Compression Test	0- 700 mm
6	Clearance Between column	500 mm
7	Ram stroke	200 mm
8	Power supply	3 Phase, 440Volts, 50 cycle. A.C
9	Overall dimension of machine (L*W*H)	2100*800*2060
10	Weight	2300Kg

Fig. Experimental testing of foot

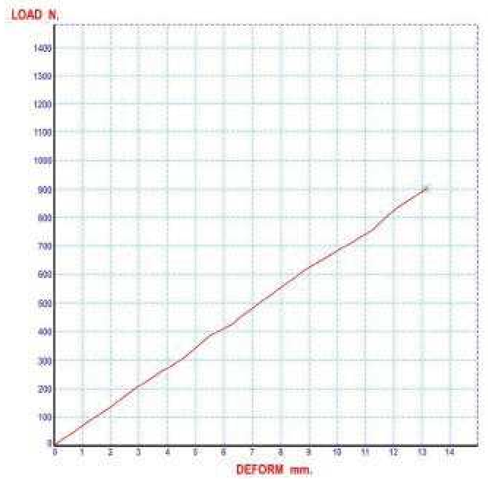


Fig. Experimental results

As per experimental test we applied the 900 N load on the prosthetic foot and find out the deformation observed in the foot. The maximum deformation observed is 13 mm approximately.

CONCLUSION

- Study on 3D printing technologies and additive manufacturing process. Learn about prosthetic foot and material used for prosthetic foot and different application of foot.
- Perform static analysis of prosthetic foot using Static structural tool with the help of ANSYS software.
- Perform static analysis to find out total deformation and equivalent stress generated on prosthetic foot using different materials. Existing material used for manufacturing prosthetic foot for child is plastic. We replace this material with PLA and ABS.
- The total deformation and equivalent stress using different material is as given below

Sr. No	Material Used	Equivalent Stress (Mpa)	Total Deformation (Mm)	Weight (Kg)
1	PLASTIC	63.92	41.09	0.329
2	ABS	64.36	13.45	0.36
3	PLA	64.44	23.65	0.429

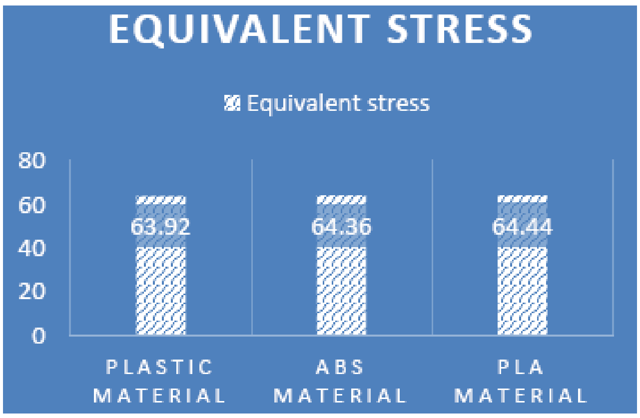


Fig. Comparison of equivalent stress

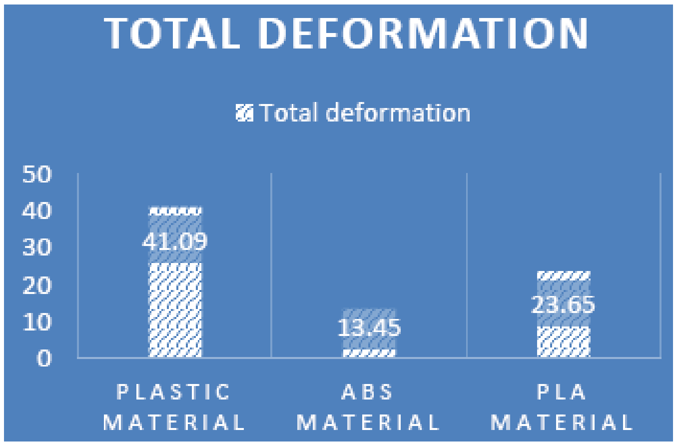


Fig. Comparison of total deformation

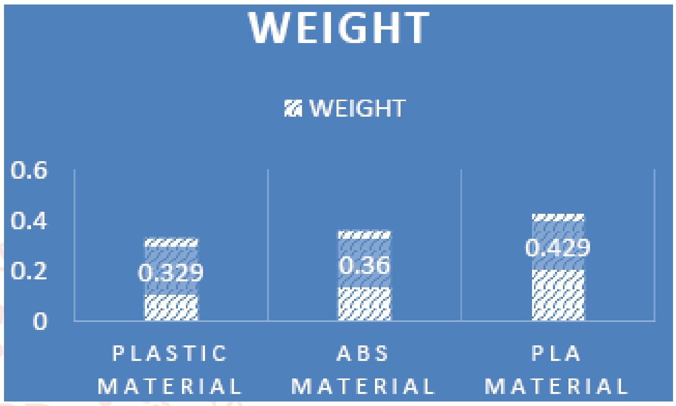


Fig. Weight comparison

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