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Finite Element Analysis of Different Fused Deposit Materials Utilised in Fabrication of Elbow Orthosis

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Abstract*: *Present work aimed to analyse the mechanical properties of various fused deposit materials used in the fabrication of elbow orthosis with the help of simulation. Four materials introduced from ANSYS Engineering data library were analysed, namely Nylon 6/6, ABS, HIPS and Polycarbonate (PC). The structural analysis of elbow orthosis helps us to investigate various materials working life. The orthosis was subjected to 20Nm of torque at the elbow joint. In the present work, the elbow orthosis finite element model was developed using SolidWorks 2017 and further analysed with the ANSYS 2019 R1 academic workbench. The result showed that ABS could withstand 628.31 MPa of equivalent stress which was maximum as compared to other materials and has a total deflection of 3.3817 mm, which indicates it can be used in fabrication of the elbow orthosis.

Keywords: Orthosis, Fused deposit materials, finite element analysis (FEA), static structural analysis.

I. INTRODUCTION

Orthoses and protheses (O&Ps) are vital tools for helping disabled individuals. An orthosis is an externally employed device used to adjust the structural and functional characteristics of the neuromuscular and skeletal system [1]. Orthoses also mentioned as braces, apply force to the body and are intended to satisfy the biomechanical requirements of patients with neuromuscular and musculoskeletal impairments that result in disability and functional restriction. The force, application location, and force control all contribute to orthosis effectiveness. Orthoses enhance the capacity of the user to work and boost their quality of life. Each orthosis has specific purposes of maintaining or correcting the alignment of the body segment, helping or resisting joint motion during the gait of the person, relieving or redistributing weight-bearing forces, protecting against external stimuli, restoring mobility and minimising deformities. A prosthesis is a medical device replacing a missing portion of the body (arm, hand, foot, or leg), due to congenital disabilities, trauma or disease [1].

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The American Academy of Orthotists and Prosthetists has estimated a total of 10 million individuals using O&P by 2020 [2].

For clinics, the Additive Manufacturing (AM) of O&P could simplify the process, increase the flexibility in design, reduce the labour cost, lessen the materials wasted, and save patients' time by reducing the number of clinical visits. Selective laser sintering (SLS), an AM technology, was used to make orthosis of the foot [3], prosthetic sockets [6, 7], and prosthetic feet [5]. Faustini et al. [4] tested the stiffness, strength and energy dissipation of Ankle Foot Orthoses (AFOs) fabricated by three SLS materials. Pallari et al. [6] attempted to optimise the topological structure of AFO using a static loading. Schrank and Stanhope [7] examined the dimensional accuracy of AFOs fabricated by SLS and showed that a sub-mm tolerance could be achieved. Creylman et al. [8] performed clinical studies on SLS AFOs and demonstrated that SLS AFOs have at least equivalent performance as compared to hand-crafted AFOs. SLS is a standard AM technology which provides fine details with adequate throughput. However, the high material and manufacturing costs using SLS hinder its applications in AM of O&P. Fused deposition modelling (FDM), on the other hand, is a more affordable AM technology suitable for O&P fabrication in clinics [9].

In the present work, the mechanical properties of different fused deposit materials used in elbow orthosis fabrication were studied using the finite element method. Finite element model was created to estimate total deformation, equivalent stress and equivalent elastic strain developed in the elbow orthosis fabricated with different fused deposit materials under static load conditions. FEA results will provide the guidelines for material used in the fabrication of elbow orthosis.

II. OBJECTIVE

The prime goal of the present work was to compare the mechanical properties of different fused deposit materials. Specifically, the objective was to compare (i) the total deformation (ii) the equivalent stress and (iii) the equivalent elastic strain developed in elbow orthosis fabricated using different fused deposit materials.

III. METHODOLOGY

In execution of the present work following steps were followed: (a) Kinematics and kinetics of the elbow, (b) 3D CAD model of the elbow orthosis and (c) Analysis of different fused deposit materials.

A. Kinematics and Kinetics of the elbow

The elbow joint's role is to flex and extend the arms to capture and reach items. 00 of elbow extension to 1500 of elbow flexion is elbow range of motion (ROM). ROM of the elbow joint was evaluated with the help of goniometer. Although the elbow is not supposed to be a weight-bearing joint, it continuously sustains large loads during daily activities. Strength analysis of both left and right elbow joint was calculated by fixing the elbow at different flexion angles (00-1200), and volunteer was asked to perform flexion and extension movements. The maximum load of 116 N act on the elbow joint when the elbow was fixed at 900 and extension movement is performed [10].

B. 3D CAD model of the elbow Orthosis

Computer-aided geometric model of elbow orthosis was generated by using a software called SolidWorks® Premium 2017. Forearm and upper limb of the elbow orthosis were created separately in part module of SolidWorks, as shown in figure 1 and figure 2.

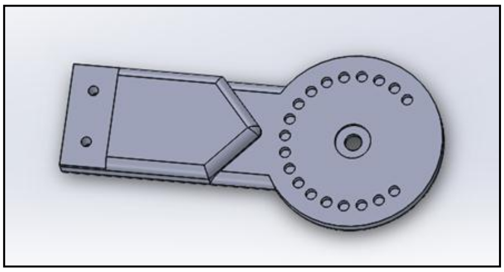

Fig.1. CAD model of forearm

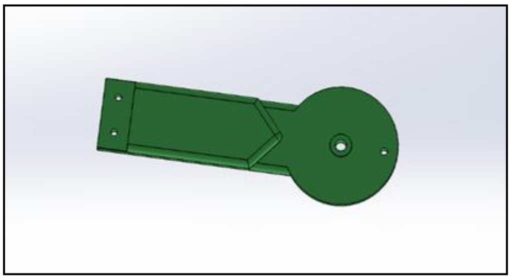

Fig.2. CAD model of Upper limb

After creation, both the CAD models were assembled in the assembly module of SolidWorks, as shown in figure 3.

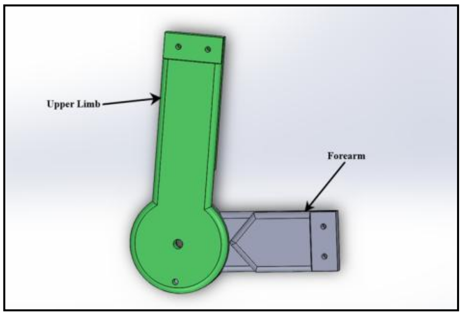

Fig. 3. CAD models assembly

C. Analysis of different fused deposit materials

ANSYS 2019 R1 academic was utilised for analyses of different materials used in the fabrication of elbow orthosis. A project in Ansys workbench was divided into seven steps. They are: i) Analysis system, ii) Engineering data, iii) Geometry, iv) Model, v) Setup, vi) Solution and vii) Results.

1) Static Structural analysis

The most common application of finite element analysis was structural analysis. The impact of steady load circumstances on a structure is calculated by static analysis. Ignoring the effects of other forces such as inertia and damping forces resulting from time-varying charges. However, static analysis can embrace constant inertia loads (such as rotational and gravity speeds) and time-varying loads that can be approximated as static equivalent loads (such as static equivalent wind).

The materials were selected for the elbow orthosis through the Engineering data library. The library contains all the major elements with different properties like linear materials, explicit materials, hyperelastic materials, etc. ABS, nylon 6/6, polycarbonate (PC) and HIPS materials were selected to carry out the analysis. Table 1 illustrates the mechanical characteristics of the materials selected for the elbow joint analysis.

Table 1 Material properties used for analysing elbow Orthosis

S.No.	Material	ρ (Kg/m^3)	α (c^{-1})	Y (Pa)	Tensile yield strength (Pa)	Tensile ultimate strength (Pa)
1	ABS	1040	9.55E+05	2.38E+09	4.15E+07	4.42E+07
2	NYLON 6/6	1140	0.000128	1.48E+09	5.71E+07	6.47E+07
3	PC	1200	0.000122	2.38E+09	6.21E+07	6.74E+07
4	HIPS	1040	7.95E-05	1.72E+09	2.80E+07	2.92E+07

ρ=density, α=Coefficient of thermal expansion, Y= Young's modulus.

The model of elbow orthosis was discretised by programmed controlled mesh, as shown in figure 4.

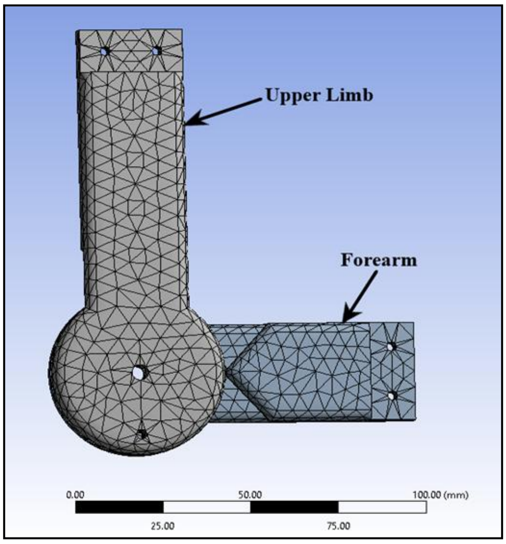

Fig.4. Model after Meshing

2) Applied Boundary conditions

After importing the 3-D geometry into the ANSYS workbench, and the materials, contacts, and joints were defined. The various solver settings were chosen to solve the defined problem for the proposed outcomes. The maximum load of 116 N act on the elbow orthosis when the elbow was fixed at 900 and extension movement was performed [10]. The force has to be converted into torque for the accurateness of the analysis.

Torque= Force * Perpendicular distance

Distance between hand and elbow joint, perpendicular distance = 0.17241 m

Therefore, Torque= 116* 0.17241 Nm

= 20 Nm

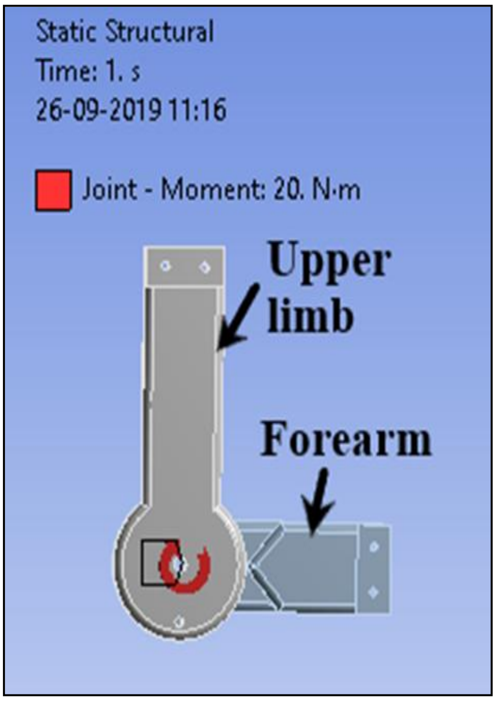

Fig. 4. Boundary conditions applied on elbow orthosis

The forearm was fixed with the ground, and 20 Nm of torque applied on elbow revolute joint. Also, the upper arm attached with the hole present in the forearm to lock at an angle of 900. Figure. 4 illustrates the boundary conditions applied on the elbow orthosis.

IV. RESULT AND DISCUSSION

Different fused deposit materials used in the fabrication of elbow orthosis analysis were done with the help of ANSYS workbench. In the analysis, the forearm was fixed with the ground, and 20 Nm of torque was applied on the elbow revolute joint. The material of the elbow orthosis was changed from the material library present in ANSYS workbench. Table 2 illustrates the results of the assessment.

Table 2 Result of different fused deposit materials

S.No	M	σ (MPa)		s (mm/mm)		l (mm)	
		Mx	Av	Mx	Av	Mx	Av
1	NYLON 6/6	618.23	7.91	0.43	6.29E-03	5.4562	1.15
2	PC	621.37	7.93	0.27	3.92E-03	3.3957	0.72
3	ABS	628.31	7.8595	0.27	3.87E-03	3.3817	0.71
4	HIPS	619.14	7.91	0.37	5.41E-03	4.6961	0.99

M= Materials, σ= Equivalent stress, s= Equivalent strain, l= Deformation, Mx= Maximum, Av= Average

Maximum of 5.4562 mm occurs in NYLON 6/6, which is not appropriate for elbow orthosis. NYLON 6/6 has a maximum equivalent strain of 0.43 mm/mm and can withstand 618.23 MPa equivalent stress. ABS have maximum equivalent stress of 628.31 MPa and 0.27 maximum equivalent elastic strain. Figure 5 is showing total deformation, equivalent stress and equivalent elastic strain in the elbow orthosis fabricated with ABS material.

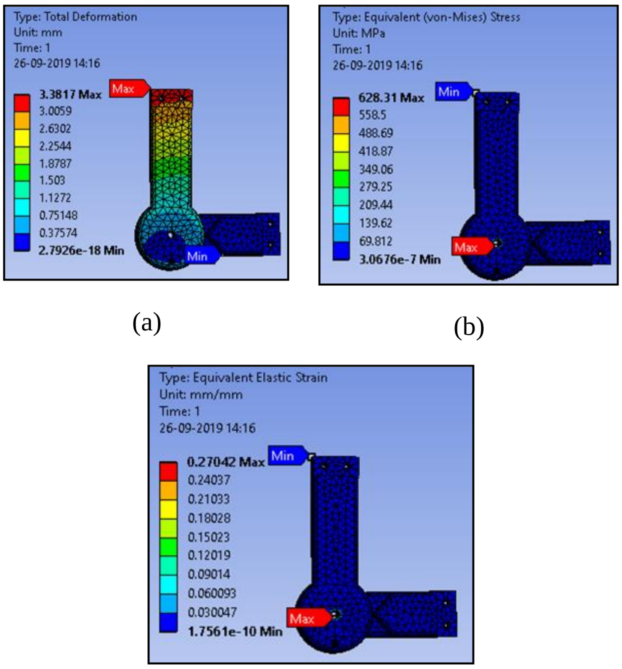

Fig. 5. (a) Total deformation, (b) Equivalent stress, and (c) Equivalent elastic strain in the elbow orthosis fabricated with ABS material

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V. CONCLUSION

In this paper, mechanical properties of different fused deposit materials utilised in fabricating elbow orthosis are analysis with the help of ANSYS workbench. From the simulation, it shows that ABS material can withstand 628.31 MPa of equivalent stress which was maximum as compared to other materials. The ability of ABS to withstand maximum equivalent stress with total deflection of 3.3817 mm makes it optimum material in the fabrication of elbow orthosis. The fabrication parameters and cost comparison will be conducted in future work.

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