International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 6, Issue 1, pp: (18-22), Month: April - September 2018, Available at: www.researchpublish.com

Materials investigation for lower limb Prosthetic socket

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Abstract: **The prosthetic socket plays an essential role in since it forms the mechanical interface between the residual limb (stump) and the prosthesis. Selection of the socket material greatly influences the mechanical performance of the socket. The objective of this study which is to investigate the performance of candidate materials (Teflon and and Polyvinyl chloride) in manufacturing prosthetic sockets. Using computer-aided design and manufacturing (CAD/CAM) processes and 3D scanner, a model of a prosthetic was generated. The model was investigated using finite element analysis. The socket performance in terms of stress, strain and safety factor were calculated and compared with the performance of sockets made of conventional polyethylene (HDPE) and Polypropylene (PP) materials.**

Keywords: **amputee, prosthesis, prosthetic socket, biomedical engineering, biomechatronics, and rehabilitation.**

1. INTRODUCTION

Prosthesis is a device that compensates for the missing part in the human body. Prosthetic socket is the mean of load transfer between the prosthesis and the residual limb (stump) and it is usually made of laminated and thermoplastic materials. The material selection (strength, weight, manufacturability, cost, etc) greatly influences production of the prosthetic sockets [1]

A number of work was carried out to investigate performance of different materials used for prosthesis socket fabrication such as HDPE, PP, and polyethylene terephthalate glycolate (PETG) [1 and 2]. To capture a 3D CAD model of prosthetic socket which could be used later for finite element analysis, 3D printing was implemented successfully [3,4, and 5]. Finite element analysis was applied in the literature to design and improve the performance of prosthetic sockets [2,3,6, and 7]

This work aims to investigate the suitability of different materials (PTFE and PVC) to manufacture prosthetic sockets. A positive cast of prosthetic socket manufactured by the National Authority for Prosthetics & Orthotics (Khartoum,Sudan) was borrowed and a 3D CAD model was obtained for it using 3D printing technique. Finite analysis was carried out on the 3D model to investigate the performance of PTFE and PVC materials. Bothe materials were used in different medical applications so they proved to be biocompatible. PVC is the most widely used plastic resin in

medical devices over the last 50 years with no known adverse or toxic effects. There are many advantages of PVC in medical applications other than the low cost, such as high durability and strength at low temperature, chemical resistance, biocompatibility, and it is easily welded to other plastics [8]. PVC was proposed for cosmetic gloves for articulating hand prostheses [9].

On the other hand, certain grades of PTFE also proved to be biocompatible to encapsulate the implantable devices [10]

The performance of PTFE and PVC materials for prosthetic socket is presented in this work and it compared with conventional polyethylene (HDPE) and Polypropylene (PP) materials.

2. MODELLING THE PROSTHETIC SOCKET

To model a prosthetic socket for finite element (FE) analysis, a ready-made socket was used [see Figure.1 for the prosthetic socket and positive cast]. Figure.2 shows FE model of prosthetic socket and the fix locations. National Authority manufactured the socket for Prosthetic (NAP) in Sudan for a person weighing 100 kg for amputation above the right knee. The socket was 3D scanned by passing the scanner carefully through the desired surfaces, to obtain a three-dimensional numerical model for FE analysis using SolidWorks. Table.1 presents the main parameters of the SolidWorks prosthetic socket model. The applied force as a result of weight was assumed to be 80 kg. This is despite the fact that the socket is expected to carry much less weight (50 kg if the load is equally distributed). The weight force was applied vertically while the bottom of the socket was assumed to be fixed (having no degree of freedom).

Four different materials were investigated. The materials are Teflon (PTFE), polyethylene (HDPE), Polypropylene (PP), and Polyvinyl chloride (PVC). The values used for mechanical properties of the four investigated materials are presented in Table.2

Figure 1: Image of a) prosthetic socket and b) positive cast

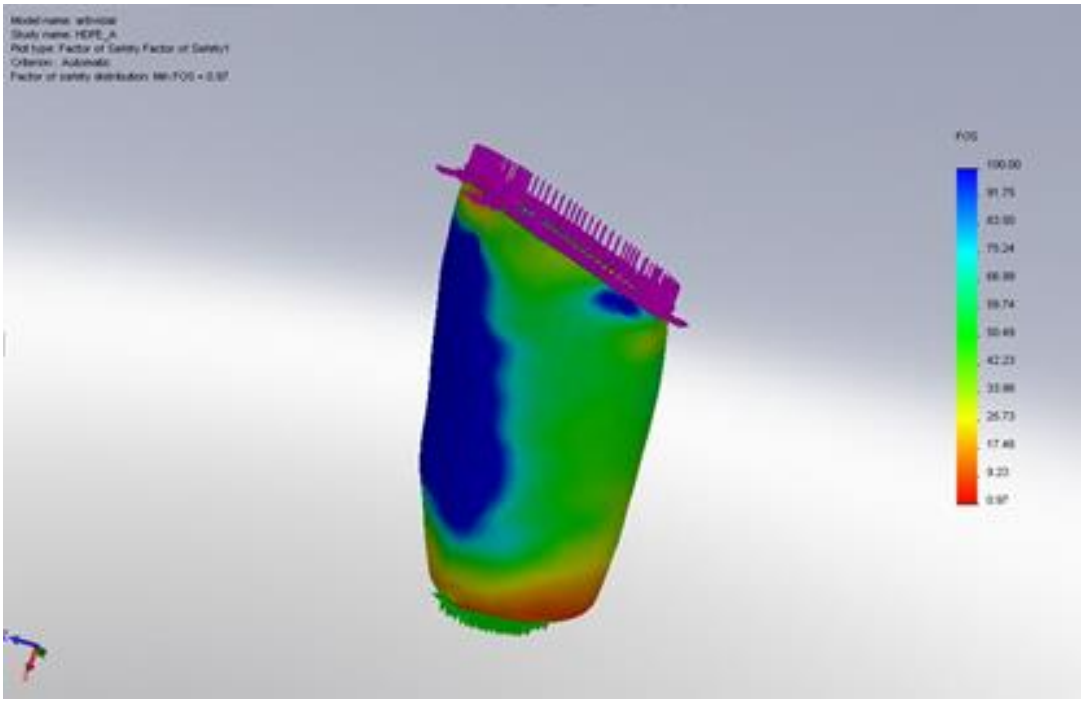

Figure 2: FE prosthetic socket model showing the fix locations

Table 1: Detailed parameters of the FE model for prosthetic socket.

Parameters	Details
Analysis type	Static
Mesh Type	Solid Mesh
Solver type	FFEPlus
Zero strain temperature	25 0C
Friction	Off
Material Model Type	Linear Elastic Isotropic
Mesher Used	Standard mesh
Element Size	8.2742 mm
Number of elements	34,882
Number of nodes	68,518

Table 2: Mechanical properties of prosthetic socket investigated materials

Property	**PTFE**	**HDPE**	**PP**	**PVC**
Elastic modulus (N/m^2)	60	70	90	15
Poisson's ratio	0.46	0.42	0.42	0.42
Mass density (kg/m^3)	2250	950	890	1400
Tensile strength (N/m^2)	30	30	32	63
Yield strength (N/m^2)	20	81	84	83

3. RESULT AND DISCUSSION

Analysis using SolidWorks FE software was carried out for yield stress, strain, and safety factor. Four different materials were investigated. The materials are Teflon (PTFE), polyethylene (HDPE), Polypropylene (PP), and Polyvinyl chloride (PVC). The applied force weight of a 80 kg person. The volume of the socket was calculated to be 725 cm3 where the mass varied from 1.6kg for the PTFE to 0.6 kg for the PP as shown in Table.3. The performance of the four materials is presented in Figures 3 to 5. For example, Figure.1 indicates that HDPE socket as well as PTFE socket failed in terms of yield stress while on the other hand the PVC socket has a maximum stress of 23 MPa but it could stands up to 53 Mpa. Figure.2 shows PVC socket has the lowest stain value (0.009) while the polypropylene socket has the highest value (0.016). Conducting safety factor analysis as in Figure.3 shows that all sockets have safety factor greater than one except for the PTFE socket (0.79).

Table 3: socket mass for different investigated materials

Calculated mass	**PTFE**	**HDPE**	**PP**	**PVC**
	1.6	0.7	0.6	1.0

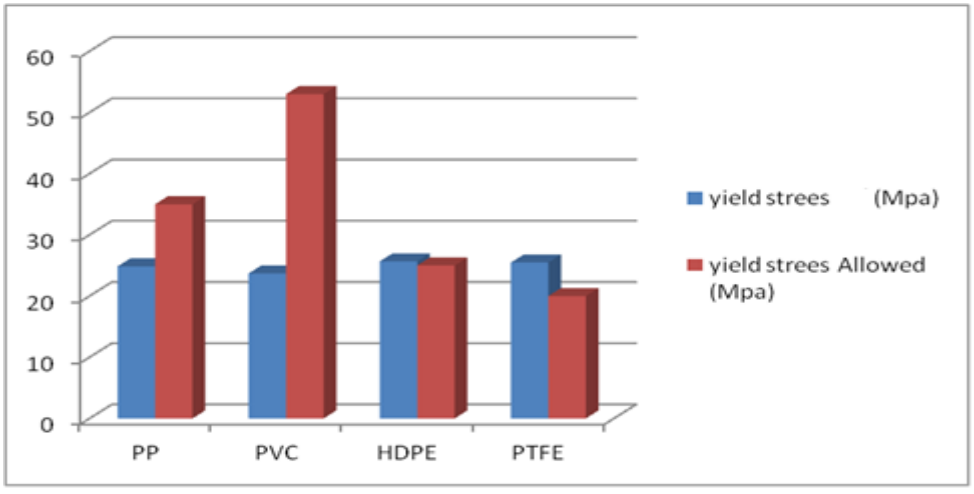

Figure 3: Stress analysis for prosthetic socket material

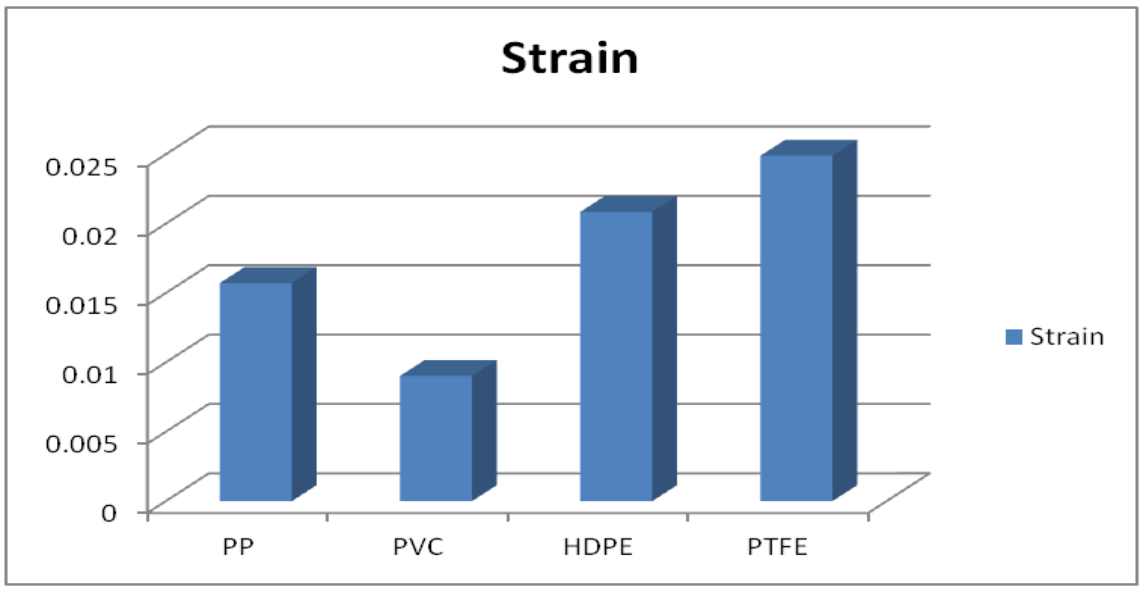

Figure.4: Strain analysis for prosthetic socket material

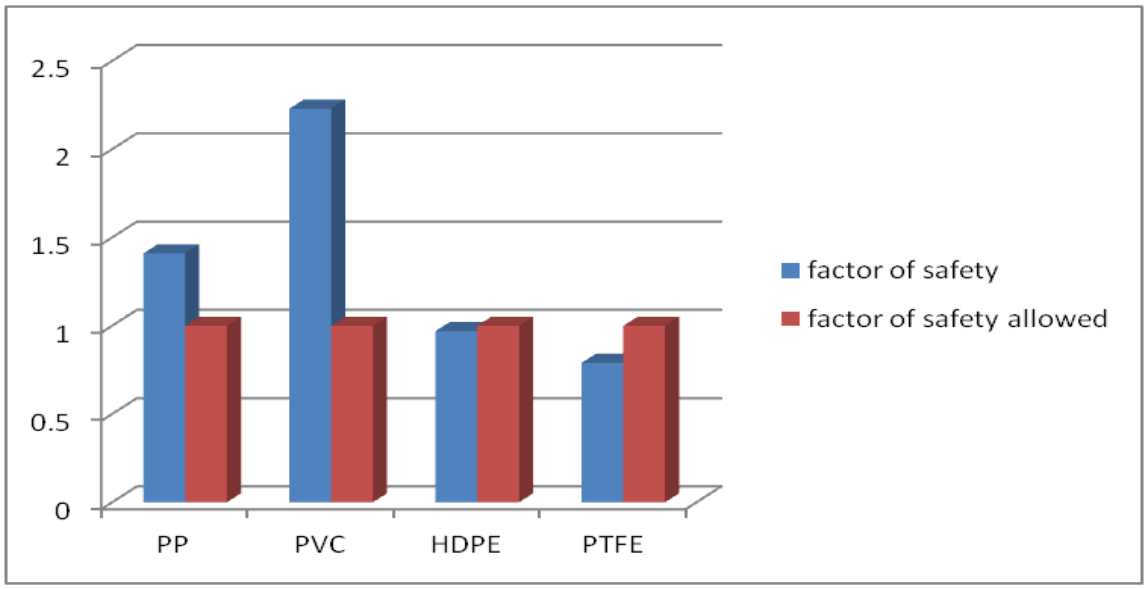

Figure.5: Safety factor analysis for prosthetic socket material

4. CONCLUSIONS

Teflon and Polyvinyl chloride materials were investigated as alternative materials for prosthetic socket. Their performance was compared with performance of sockets made by conventional Polyethylene and Polypropylene material. The analysis carried out in this work indicates PVC performed best, in terms of strain and safety factor, among the four investigated material besides their availability and cost advantages while PTFE material showed poor performance. The procedure presented in this paper can be used to investigate other materials as well as other parameters related to prosthetic sockets.

ACKNOWLEDGEMENT

Authors would like to thank National Authority for Prosthetics & Orthotics (Khartoum, Sudan) for providing us with positive cast (plaster model) which was used to extract of CAD model. Thanks for at Tafra Engineering Company (Khartoum,Sudan) for using their facilities to carry out 3-D model and Engineers Abuagla Suliman and Gamal Gadelkareem for their assistance. Finally we would like to thank AWTAD Company for Prosthetics & Orthotics for their help.

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