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Material Selection for Modeling of Intervertebral Disc

A Swamy[1]

[1] Ethiopian institute of Technology – Mekelle University, Department of Mechanical Engineering, Mekelle, Ethiopia
Email: amitswamy1@yahoo.co.uk

Abstract: ***"Lower back pain" is an extremely common condition and very difficult to diagnose and treat. Computer models may help in the diagnosis, but need validation. This paper discusses the basic material selection for intervertebral disc for Lumbar spine (L1-L2), by changing the different intervertebral disc materials. The appropriate material is modeled to physiologically simulate the movements of vertebral body and intervertebral disc. The entire modeling will consist of various parameters that are used for the design viz, geometry, material properties and loading constraints of the lumbar spine. The vertebral bodies are manufactured from Acrylonitrile-butadiene-styrene (ABS) P400 resin that has similar strength to vertebral bones. The stress strain curve for different intervertebral disc material indicates that PU-foam has better compressive properties with a lower elastic modulus, thus selected.***

Keywords: Vertebral bodies, Intervertebral disc, material, Elastic modulus, prostheses

1. Introduction

Low back pain is seen in different age groups as a major cause of absenteeism, physical disability and one of the highest contributors to compensation claims across the globe. In the UK over 1 million people are disabled by it, and in 1997-8, over 119 million days a year were lost due to registered disability caused by back problems [1]. 13% of unemployed people say that back pain is the reason they are not working. The cost of back pain to the National Health Services and through lost production is in excess of £5M [2].

At present surgeons can frequently cure and alleviate lower back pain using a number of different techniques available to them. But it is the initial diagnosis that can be very problematic due to the intricate and complex 3-D skeletal structure and its multiple degrees of freedom. The best imaging techniques cannot provide sufficient detail of the spine with realistic loads. Also animal models are proposed for in vitro mechanical testing, but due to the high cost involved and ethical issues, this is now becoming increasingly difficult.

Diagnosis of back pain requires detailed imaging of the patient's spine in realistic positions and loading conditions, but with the current technology this is not currently possible. The scans have to be taken with the patient in supine position, when the spine is unloaded. The long term goal of this research is to develop a new technique whereby patient specific spine models are developed from standard scan data, loaded and then used to modify the original images of the spine and surrounding soft tissues to reveal the movement of patients spine under loading. So, the purpose of this research project is to develop a patient specific laboratory spine.

2. Intervertebral Disc Implants

Intervertebral disc prostheses usually comprise of two metal plates and a cushion interposed between the plates as shown in figure 1. The cushion includes a compressible body having two ends in contact with the plates. The two ends of the disc geometry have one end that is freely displaceable to the plate and the other fixed. Thus the prosthesis imitates and approximates the mechanical properties of a healthy natural intervertebral disc.

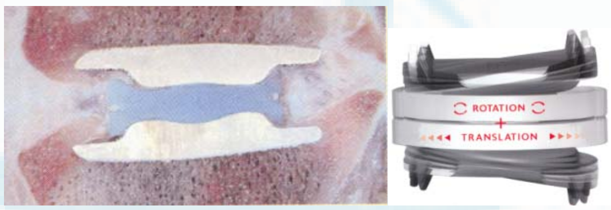

Figure 1: Mechanical discs with translation and rotation [6].

3. Material selection and testing for intervertebral disc

3.1 Vertebral Bodies

The vertebral bodies of the physical model were manufactured from Acrylonitrile-butadiene-styrene (ABS) P400 resin. This was chosen because ABS is tough, resilient and easily moulded [7]. The Young's modulus for actual vertebral bodies ranges from 1.5 to 3 GPa [3] while the Young's modulus of ABS P400 is 2 GPA and for the simplified vertebral bodies manufactured using FDM is 2.48 GPa [3].

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Table 1: Comparison of potential materials for the intervertebral discs

Name of material	*Manufacturer*	*Hardness (Scales)*	*Tensile Streng. (MPa)*	*Tensile modul (MPa)*	*I.D.*
AD 25 A/B	ACC	29 (A)	5.2	-	AD 25 A/B
RTV 940	ACC	38-42 (A)	>4.4	-	RTV 940
Silcoset 101	ACC	55 (A)	4.13	-	Silcoset 101
Silicone foam	Zotefoam	1-5	2.41	-	Silicone foam
PU-foam	TW-foams	0-1	--	15-30	Foam

3.2 Intervertebral Disc

As in the natural spine, the vertebral bodies are much stiffer than the intervertebral discs, the material used in the manufacture of the discs is critical to the artificial spines. Therefore a number of different materials were considered, as summarized in Table 1, which compares the values from the data sheets provided by the respective companies that were experimentally verified.

According to Siddall 2003 [4], the intervertebral bodies are manufactured from Silicoset 101. According to Fagan et al., 2001 [2] the above material (Silicoset101, Silicone Foam, RTV940, AD25) shown in table 1 were used for intervertebral disc. The hardness scale (i.e. the resistance to permanent indentation) played an important role in the selection of the material. The intervertebral disc was molded from silicone rubber was manufactured using silicone foam material and rubber material, where the ratio of rubber used in the silicone foam dictated the stiffness of the intervertebral disc [5].

Figure 2: Dynamic Mechanical Analyser (DMA) (Q800) – (TA Instruments, USA

Among the various materials shown in the table.1 the most suitable material for the disc was PU-foam, which was affordable, easily fabricated in different shapes without change in properties and with hardness between 0 to 1. The materials with higher hardness have a very high Young's modulus and have very low compression strength. The elastic modulus of the different materials was measured using a Q800 DMA (Dynamic Mechanical Analyser) – (TA Instruments, USA) shown in figure 2. Samples of the intervertebral disc materials were tested in TA instruments DMA (Q800) – (TA Instruments, USA) as shown in figure 2, to determine the Elastic modulus.

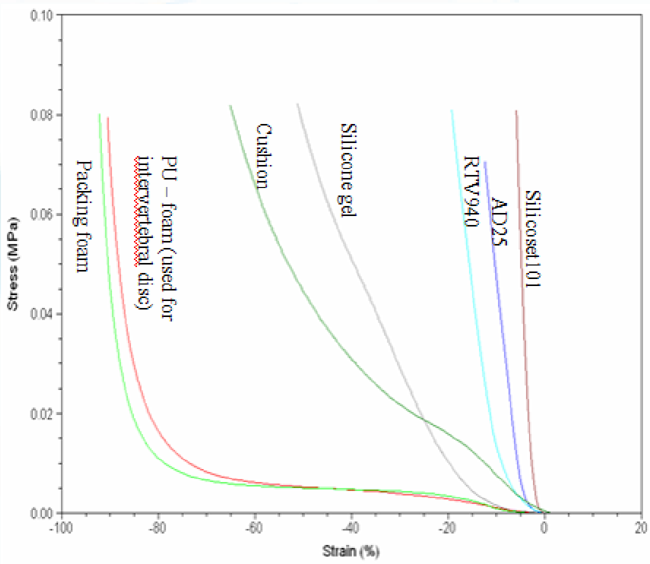

Figure 3: DMA analyses for material selection of intervertebral disc

The stress-strain graphs produced by the DMA for the different materials with similar size samples and uniform load of 1N/sec for 5 minutes steps were obtained as shown in figure3.

4. Discussion

The stress strain curve shown in figure 4 indicates that PU-foam has better compressive properties and has a lower elastic modulus i.e. the slope of stress and strain curve. The properties observed above shows that Silicoset 101, as intervertebral disc has lower compressive properties than PU-foam. These properties were further tested with an experimental analysis carried in UTM, in which a PU-foam sample was compressed and the corresponding changes in stress and strain were measured and compared with DMA results, as shown in figure 4.

A best-fit line fitted through the data points (r=0.986) showed that the slope (i.e. the Elastic modulus) was 26.67 MPa.

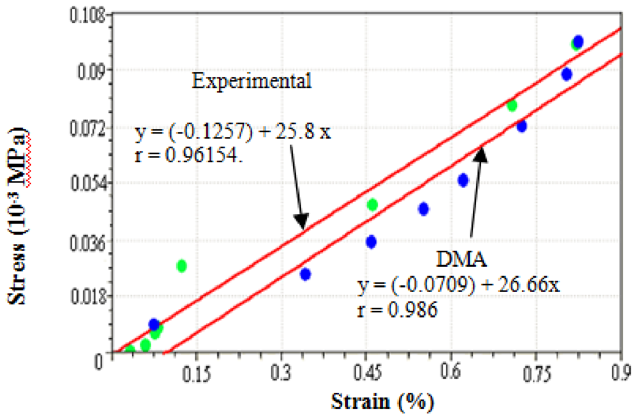

Figure 4: Experimental results from DMA analyses for calculation of stress strain behavior for PU-foam

The properties of the material were assumed to be linear elastic for simplification.

Table 2: Properties of materials used for laboratory spine

	Vertebral body	*Intervertebral disc*
Elastic's Modulus (MPa)	1500	26.7
Poisson's ratio	0.405	0.1- 0.3

Table 2 shows properties from above analysis that can be used for FE modeling.

References

[1] "The Prevalence of Back Pain in Great Britain in 1998", Health Statistical Bulletin 1999/18.
[2] Fagan MJ, Gillespie P, Julian S, Siddall S, Mohsen A., "Development of an artificial intervertebral disc for a laboratory test spine". Journal of Biomechanics, 2001. 34:S1, 58-59.
[3] Garske D and Langrana NA. . Mimicing lumbar vertebral bone architechture using layered manufacturing technology. Summer Bioengineering Conference, June 200, 25-29, Starting page #1007
[4] Siddall DJ,. "Patient specific spine models: The development of a laboratory validation spine". 2003, PhD Thesis, University of Hull.
[5] Swamy A,. "Development of laboratory spine with artificial muscles" PhD Thesis, University of Hull, 2007. http://hydra.hull.ac.uk/resources/hull:780
[6] Valdevit A. and Errico TJ.. Design and evaluation of the FlexiCore metal-on-metal intervertebral disc prosthesis. Spine, 2004, 4, 9, 276S-288S.
[7] Zein I., Hutmacher DW., Tan CK., Teoh SH.. Fused deposition modeling of novel scaffold architectures for tissue engineering applications. Biomaterials. 2002, 23, 1169 – 1185.

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Author Profile

Amit Swamy is a PhD graduate from University of Hull, UK in 2007. He has completed his post-doctoral research in University of Hull in 2008. He has also worked for various research projects in UAE and Oman for Bhatia brothers' joint venture with Rollys Royce, UK. He is now working with Ethiopian institute of technology, Mekelle, Ethiopia.