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THERMOPLASTIC ELASTOMER INFILL PATTERN IMPACT ON MECHANICAL PROPERTIES 3D PRINTED CUSTOMIZED ORTHOTIC INSOLE

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ABSTRACT

Percentage of infill pattern is one of the important parameter in the 3D printing process when flexibility and cushioning is critical. This study was done by focusing on the structure of insoles foot orthosis produced using 3D printing which is one of the methods in additive manufacturing. Thermoplastic elastomer namely Filaflex and NinjaFlex which was printed by using Flashforge 3d printer was in order to determine the mechanical properties of samples with variations of the percentage infill patterns. In this study, the samples went through three type of testing, which are tensile test, flexural test and hardness strength for infill pattern of Filaflex was higher value compared to the ninjaflex where 284.6 N for maximum force with 70% of infill of tensile strength of Filaflex and flexural strength for infill pattern 2.28 N for flexural force with 80% of infill show the effective result of Filafex compared to Ninjaflex result. The lowest hardness of Filaflex 7.8 shows the best structure hardness of foot insoles structure.

Keywords: flexible filament, thermoplastic elastomer, infill pattern, orthotic insole, 3d printing.

INTRODUCTION

Orthotics insole is generally used for the relief of foot pain, heel pain, shin pain, knee pain and back pain. Often, a biomechanical mal-alignment or lack of stability from the foot region can cause abnormal loads on the tissues of the foot and heel, shin, knee or back pain can develop as a result. Custom insole products are frequently used to relieve plantar pressures.

Since 1988 additive manufacturing (AM) has become an important part of product development. The AM process involves rapidly building a physical model of a part, layer by layer, based on a 3D CAD drawing. Medical is one of the new fields that applied AM technologies for designing medical devices development and instrumentation, tissue (implantation) engineering, mechanical bone replica, anthropology, forensic and prosthetic and orthotic.

For prosthetic and orthotic devices, AM field already proven gives many benefits to patients because with specific support equipment production it can help patient improving convenience and stability of their foot during walking. Orthosis divided into three types which are Foot Orthosis (FO), Ankle and Foot Orthosis (AFO) and Knee, Ankle and Foot Orthosis (KAFO). Function of foot orthotic (FO) not as to support footprint curve, but also straighten back foot structure and prevent difference in bone structure and muscle, tendon, and ligament fatigue. Besides that it is important to ensure that it works well to facilitate the function of the foot to improve efficiency in the interaction between the biomechanics of the foot and the ground. Now parallel to technology development, FO was produced by using the AM method for the purpose of time saving and the production cost.

The root of the study is based on the present materials which is used to fabricate an orthotic insole in Cheras Rehabilitation Hospital. The hospital is currently fabricating orthotic insole using several materials such as Nora, Plasterzote and P-lite. They are fabricating using the conventional method. The most widely recognized conventional methods involve vacuum forming the thermoplastic sheet around a adjusted, corrected positive plaster cast of the anatomy of interest, next the process is cutting away the unwanted material to form the orthosis. Additive manufacturing (AM), has the ability to surmount these limitations and allow healthcare professionals involved in the prescription of these types of devices the opportunity to explore truly novel orthotic design features

The intention of this study is to develop specimens using Flashforge machine. Fused deposition modelling (FDM) is widely used additive manufacturing (AM) technology. Currently, 3D printing has become more popular in industrial; this is because various researches were carried out to produce product resilience that is high when printing process. Apart from affecting resilience, it also gave a saving to printing material and time for fabricating a product. Figure-1 represents the schematic of the FDM process. In this process the thermoplastic polymers are used as raw material and the objects are formed by extruding the thermoplastic polymer supplied through a coil (A) by a temperature controlled extrusion nozzle (B) that travels in X, Y and Z directions (C) to create a two dimensional layer. After the platform lowers, the nozzle deposits another, layer upon the previous layer and this process is repeated until completion of the part.

Therefore mentioned literature review reveals that most of the investigations contain approaches about the reduction of surface roughness, dimensional tolerances and increasing mechanical properties. Very few attempts have been made to determine the effect of part deposition orientation on mechanical properties together with production cost

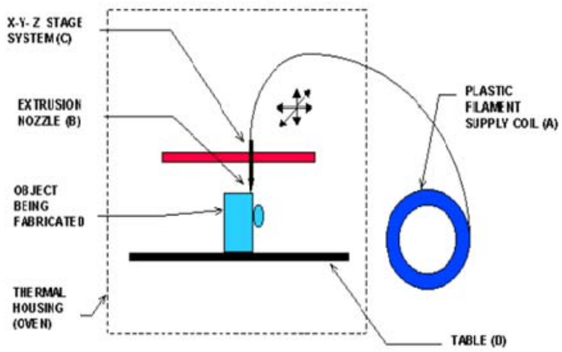

Figure-1. Schematic of fused deposition modeling (FDM) technique.

Filling is a factor used to fill up empty space within one object, it refers to the density. Infill pattern can be measured by the percentage, so the objects produced at 100% infill volume represent 100% of the density of the object. The higher percentage of the infill process to create a more solid object, and the longer time it takes to complete it. When the lower percentage of infill pattern, the process becomes lighter and faster than the infill pattern at the highest percentage. A 3D printer can make filling in some patterns such as linear, hexagonal, Moroccan star and cat fill. Filling percent may result from 10% to 100% as indicated in Figure-2 shows the hexagonal infill pattern and the infill pattern on normal insoles that commonly used.

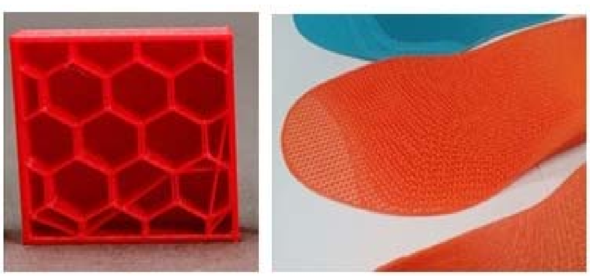

Figure-2. Hexagonal Infill patterns and printed insole.

METHODOLOGY

Material preparation

Filaflex and Thermoplastic elastomer (Ninja flex) is several types of material that consist of rubber. These materials are flexible in design, high-performance and ease of processing that has led to designers to increasingly turn as their material of choice. Figure-3 shows the Filaflex filament and Thermoplastic elastomer (Ninjaflex) characteristic of the parameter. Firstly the material for this research is Filaflex filament and Thermoplastic elastomer (Ninjaflex) filament show in Figure-4 which was machined using Flashforge. Whereas, the type of infill pattern will be used is hexagonal, and the percent infill like 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%.

CHARACTERISTIC	FILAFLEX	TPE
Diameter	1.75mm	1.75mm
Speed of printing	30-50 MM/S	30mm/s
temperature	210-230ºC	210-230˚C
density	1215 KG/M^3	1200 kg/m3
Shore hardness	Shore Hardness Type (A & D)	Shore Hardness Type (A & D)
Tensile strength	39MPA	34.5 MPa
Platform temperature	0˚	110˚

Figure-3. Characteristic of parameter.

(a) (b)

Figure-4. a. Filaflex b. Ninjaflex.

Flashforge 3D printer

The Flashforge 3D Printer is the easiest, fastest, and most affordable tool for making professional quality models. The Flashforge sets a new standard in resolution and accuracy (true-to-life models) and build volume (size of the model). Constructed with an industrial strength pressed steel frame, which has advantages for both form and function of the machine looks perfect in an office, lab, workbench, and even the living room and is durable enough to withstand high 3D printing speeds. The Flashforge Desktop 3D Printer is compatible with Mac, Windows, and Linux operating systems. MakerWare Desktop 3D Printer software is used as a communication medium between computer and Flashforge. MakerWare is free software that includes everything, including a lightning fast tool path engine and a brand new user-friendly interface. Standard test specimens were prepared based on ISO 37 for tensile test, ASTM D2240 for hardness test and ISO 178 for flexural test. There are sixty specimens had been machined using Flashforge Table-1 show total specimen used in this research.

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Table-1. Total of specimen.

Type Of Testing	Tensile Test		Flexure Test		Hardness Test	
Number Of Specimen	Fila flex	Ninja Flex	Fila flex	Ninja Flex	Fila flex	Ninja Flex
	10	10	10	10	10	10
Infill Density For This Experiment	i. 10%		i. 10%		i. 10%	
	ii. 20%		ii. 20%		ii. 20%	
	iii. 30%		iii. 30%		iii. 30%	
	iv. 40%		iv. 40%		iv. 40%	
	v. 50%		v. 50%		v. 50%	
	vi. 60%		vi. 60%		vi. 60%	
	vii. 70%		vii. 70%		vii. 70%	
	viii. 80%		viii. 80%		viii. 80%	
	ix. 90%		ix. 90%		ix. 90%	
	x. 100%		x. 100%		x. 100%	
Number Of Specimen	20		20		20	
			Total Of Specimen		60	

Equipment for testing

Tensile test is the most basic and common materials test method. It's provided data on the ultimate strength, modulus, elongation, toughness, and also yields strength. Tensile test is carried out at both low and high temperatures in order to investigate if there is any difference in the data gained due to this parameter. The temperature that are commonly used are around -40˚C and also 200˚C for low and high temperature respectively. Standard testing for rubber or elastomer materials are ISO 37

ISO 37 describes a method for the determination of the tensile stress-strain properties of vulcanized and thermoplastic rubbers. The properties which can be determined are tensile strength, elongation at break, stress at a given elongation, elongation at a given stress, and stress at yield and elongation at yield. The measurement of stress and strain at yield applies only to some thermoplastic rubbers and certain other compounds.

Universal testing machine in compliance with ISO 5893. The machine shall be capable of performing the test at rates of traverse of 100mm/min, 200 mm/min, and 500 mm/min. By means of our rubber testing expertise and modular product design, we will help find the testing solution that is right for you. Give one of our application engineers a call today for help with creating the best budget and testing plan according to ISO 37.

Testing of bending or flexural properties of this material is quite common to find out its behaviour. The standard flexural is either three of four point types which used to test rigid and semi-rigid thermoplastic rubber materials. The technique used for this study is flexural with three point bending.

The term "flexural strength" or "modulus of rupture" is used for the surface stress of a material when breaking occurs. In other words, the flexural strength can be defined as the ability of a material to withstand bending forces that applied perpendicular to its longitudinal axis. The resistance to elastic deformation which commonly known as modulus of elasticity is more commonly called stiffness. Testing standard that is suitable to investigate the flexural properties of these materials is ISO 178.

The most generally utilized gadget is a shore hardness meter to measure hardness of a material. Durometer Hardness is utilized to identify the relative hardness of soft materials, normally plastic or rubber. The measurement was taken by the penetration of a specified needle like into the material under specified conditions of time and force. The hardness value is regularly used to determine the specific hardness of elastomers or as a quality control to measure on bunch of materials.

The hardness numbers are taken from a scale of Shore A and Shore D in common, with the shore a scale being utilized for softer materials and the shore D scale utilized for harder materials. The penetration Durometer indenter into material will give the value of the hardness.

The mechanical testing such as the tensile, flexure and hardness test has been conducted. The samples are shown in Figure-5, 6 and 7. The tensile testing and flexure strength equipment was used is Universal Tensile Machine (UTM) and hardness test was used Durometer shore type D.

Figure-5. Flexure samples.

Figure-6. Tensile samples.

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Figure-7. Hardness samples.

RESULTS AND DISCUSSION

Hardness test

Table-2. Hardness results.

	Infill Percentage (%)	Materials	
		FilaFlex	NinjaFlex
Average reading (shore D)	10	7.8	23.4
	20	9.7	27.0
	30	11.3	33.2
	40	14.9	37.6
	50	16.4	44.0
	60	17.4	45.5
	70	18.2	47.5
	80	19.7	49.6
	90	21.5	52.5
	100	30.3	55.7

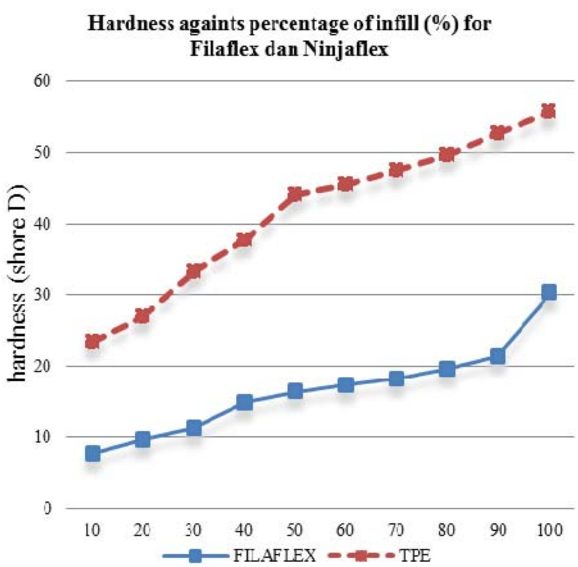

Figure-8. Hardness against infill percentages.

The graph shows hardness against percentage of infill (%) for Filaflex and Ninjaflex. The average showed the hardness of Ninjaflex is much different compared to Filaflex because Filaflex material affected by a soft structure. At 100% state where the two specimens are in a hollow structure the reading of Filaflex still low at 30.3 shore D compared to the 55.7 shore D of Ninjaflex hardness. The lower of hardness value, the more effective of the material as orthotic foot insoles.

Table-3. Hardness value different materials.

Type of material	Reading (shore D)			Average (Shore D)
	1	2	3	
Plasterzote	5.5	5.5	6.0	5.39
	5.0	5.5	5.0	
	6.0	5.0	5.0	
P-lite	10.0	11.0	10.0	12.78
	12.0	11.0	10.5	
	11.5	10.0	11.0	
Nora	4.0	5.0	5.0	7.00
	5.0	4.5	5.0	
	5.5	5.0	6.0	

After doing some testing of the hardness material such as Plasterzote, P-Lite and Nora which are the material are used at Hospital Rehabilitate Cheras as material of orthotic insoles, the result obtains shown in table 3, which the data closer to the Filaflex hardness. From that, Filaflex are the most suitable and effective material as foot orthotic insoles based on the hardness test result.

Tensile test

The graph shows the difference between Filaflex and Ninjaflex for Maximum Force (N), against the percentage of infill density (%). Based on this graph the maximum force required by Filaflex higher compared to the force required by each percentage infill of Ninjaflex.

At 70% infill pattern recorded the maximum force for the Filaflex was 284.6 N. At 100% infill of Ninjaflex recorded the maximum force of 105.5N. The graph above shows the break displacement (mm), against the percentage of infill (%) for the two materials, Filaflex and Ninjaflex. From this we know that the Filaflex material can be stretched and withstand high force before it fails, which can be say as it a highly elastic material.

Whereas the Ninjaflex material changed its elasticity properties after printing it means after heating its elastic properties had been changed due to thermal, and also may cause by the layer bonding not well. At 100% percentage infill of the break displacement recorded the highest data for the two materials was 362.8mm for Filaflex and 100.1mm for Ninjaflex. The break displacement of Ninjaflex is still low compared to the percentage of Filaflex infill pattern.

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Table-4. Tensile test reading for FilaFlex and NinjaFlex.

Infill Percentage	Maximum Force (N)		Maximum Stress (MPa)		Break Force (N)		Break Displacement (mm)	
	FilaFlex	NinjaFlex	FilaFlex	NinjaFlex	Filaflex	NinjaFlex	Filaflex	NinjaFlex
10%	247.50	53.4406	30.94	6.68008	247.44	19.2656	360.10	60.4500
20%	224.38	58.0062	28.04	7.25078	224.24	23.3625	342.30	86.2320
30%	225.02	52.9562	28.13	6.61953	248.55	36.9469	361.46	27.5670
40%	231.72	57.0156	28.96	7.12695	241.44	40.3281	318.21	51.7710
50%	259.23	64.2969	32.40	8.03711	246.001	44.5063	316.48	52.7380
60%	249.19	74.1094	31.15	9.26367	249.06	46.6375	319.55	14.5160
70%	284.61	78.9031	35.58	9.86289	284.23	40.0281	319.38	38.8330
80%	275.41	64.6062	34.43	8.07578	261.28	27.6781	342.00	16.7710
90%	262.84	77.9656	32.86	9.74570	244.656	62.6750	352.00	56.4750
100%	241.11	105.556	26.76	13.1945	250.13	101.894	362.82	100.154

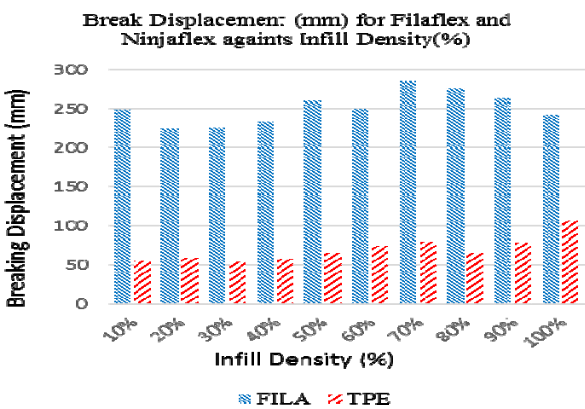

Figure-9. Break displacement against infill density.

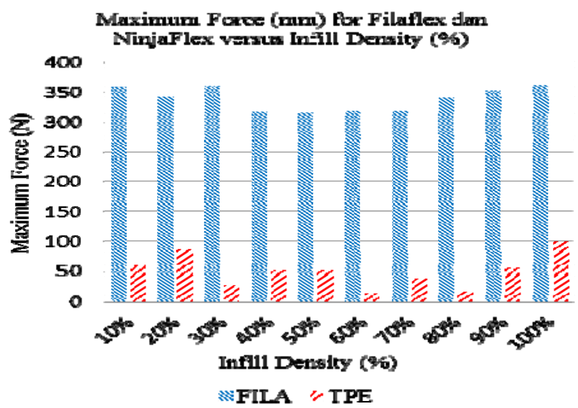

Figure-10. Graph of maximum force versus infill density.

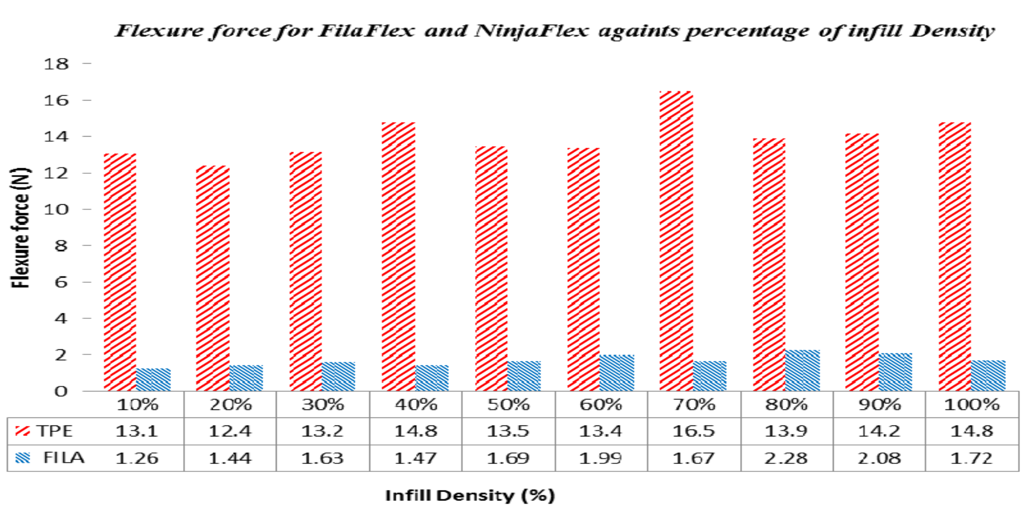

Figure-11. Flexure force for FilaFlex and NinjaFlex against percentage of infill density.

Flexural test

The graph above shows Flexure Force (N) for Filaflex and NinjaFlex against Percentage of Infill Density (%). At 70% of Ninjaflex infill pattern shows the highest bending force with 16.5 N, compared to Filaflex at 80% with 2.28 N had the highest bending force. But the lower of the flexural strength of the material one of the factors to be considered is the high level of elastic.

The bending force obtained are different as shown in the table below the graph, this shows the power of bending the resulting patterns vary according to the type of charge and is also dependent on the type of material produced. Based on the results the reading of Ninjaflex higher when compared to reading Filaflex. The resulting structure is a little tougher Ninjaflex compared Filaflex structure and elastic low levels because the material shows high readings percent in the charging pattern. Although both materials are elastic and will not break when subjected to bending forces over whom power is very important to identify the ability of a material for maximum flexibility at a point before the material is fully flexible. The lower the flexural strength of the material the better the show, as in the production of liner away one of the factors to be considered is the high level of elastic. When the level of a substance shows a high elastic is driven by the soft nature of the material structure.

CONCLUSIONS

As a conclusion, the pattern and percentage of infill pattern affects tensile strength, hardness and flexure toward a specimen produced by 3D printing machine technology FDM (Fused Deposition Modelling). Through these experiments the rubber can be printed using machines Flashforge although improvement needs to be done on the machine. In addition, we can know the mechanical properties of structural liner foot orthotic printed from various percent fill by using 3D printing machine technology FDM (Fused deposition modelling) through which the test was performed for hardness, tensile and flexure. Based on the results obtained using the percentage of filler can influence the hardness, tensile and flexural tests. According to the material, Filaflex is very suitable as insoles rather than Ninjaflex. As the final result, tensile, flexure and hardness strength for infill pattern of Filaflex was higher value compared to the Ninjaflex. 284.6 N for maximum force with 70% of the infill of tensile strength and flexural strength of Filaflex of infill pattern 2.28 N for flexural force with 80% of infill percentage. The lowest hardness of Filaflex 7.8 shows the best structure, hardness of foot insoles structure.

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