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Study of 3D Printing Layered Fiber Fabric Filaments as an Alternative to Polypropylene Materials in Ankle Foot Orthosis for Children with Cerebral Palsy

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Abstract. *This study aims to design a valid instrument for measuring the satisfaction of internal and external users on service quality provided by an institute for research and community service (LPPM) at a university. The SERVQUAL model is applied and a case study was conducted at Universitas Muhammadiyah Surakarta. Twenty-eight research attributes and twenty attributes of community services have been developed to measure the LPPM service quality based on five dimensions criteria namely tangible, reliability, responsiveness, assurance, and empathy. The developed attributes were validated by experts, e.g., head of LPPM and his staff. Further, using bivariate Pearson correlation and Cronbach alpha those attributes were tested for validity and reliability using SPSS 23. The result showed that all attributes in the instrument were valid and reliable. Furthermore, based on the Actual SERVQUAL Score (ASC), all attributes have score more than 75%, which can be classified as better than "good" according to the UMS Quality Assurance Agency (LJM). It indicates that the customers are satisfied with the services. However, based on the service quality gap analysis (i.e., gap between the perceptions and expectations of users), all statements showed negative results, which means that the perception is lower than expectation. Hence, improvements are still required especially to those attributes with high gap.*

Keywords: *actual service score, gap analysis, customer satisfaction, servqual*

I. INTRODUCTION

Cerebral palsy (CP) is a motor disability that occurs in childhood resulting in disturbances that affect a child's ability to move and maintain balance and posture. CP children in the moderate category need to use assistive devices in the form of an ankle foot orthosis (AFO) to be able to walk. AFO has a role as part of conservative therapy to reduce impaired postural motor control and strengthen muscle weakness that allows you to carry out activities of daily life. CP children in the mild category walk a little awkwardly, but may not need assistance. Up to 85% of children with CP use at least one assistive device (Sacaze et al., 2013). The use of AFO could improve gait parameters and gait balance in children with spastic CP (Shlomo et al., 2007).

The AFO design should be able to support CP children comfortably fitted individually for each child. AFO is differentiated based on the design and type of material used. Material criteria for AFO such as weight, durability, and overall aesthetics of the product must be considered when planning the orthosis. In addition, AFO can be dynamically and statically stable, has low shear strength, and is biocompatible with human skin (Griškevičius et al., 2017). Manufacturers often face problems in designing AFO functionally and economically. The problem is what materials can be used in AFO production that meets all the requirements of the brace standard, are reliable, functional, and withstand loads of movement during the period of use. The results of clinical observations that AFO is effective for some children with CP, whereas AFO can cause adverse or even detrimental effects for others (Braddom, 2006).

The use of thermoplastic polypropylene (PP) in AFO products has been widely applied in recent decades because it is lightweight, flexible, and adaptable to body anatomy. AFO products with PP materials used by CP children have

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drawbacks because these products are mass-produced while the design needs of CP children are very different. Therefore it is necessary to innovate in designing custom AFO through the application of additive manufacture (AM). The AM principle is based on a 3D printing process using a filament as the printing material. 3D printing filaments with high strength and durability such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG) and polycarbonate (PC).

The mechanical and physical characteristics of the 3D printing filament material explain that PLA has a density value of 1.24 g/cm3 and a maximum pressure of 65 MPa with the advantages of being easy to print, cheap, and applied to various applications. ABS has a density value of 1.04g/cm3 and a maximum pressure of 40 MPa with the advantages of being tough, impact resistant, and used to print spare parts. PETG has a density value of 1.23g/cm3 and a maximum pressure of 53 MPa with the advantages of an easy printing process, provides good coating adhesion, and chemical resistance, and does not smell. PC has a density value of 1.2g/cm3 and a maximum pressure of 72 MPa with the advantages of being resistant to high temperatures, easy to bend, and resistant to impact. 3D printing filaments with layers of carbon fabric or texalium fabric provide an opportunity as a replacement material for AFO products with PP thermoplastic materials.

The effect of customizing AFO materials with PP makes products thinner and can be coated with fabric materials more comfortably than AFO materials with conventional plastics (Do et al., 2014). Design customization with the application of AM in AFO products for CP children has a lot of potential as new materials become lighter, and improve biomechanical functions and comfort (Banga et al., 2020). The mechanical assessment of AFO materials using PP materials in the durability test obtained the material's weak points and the material's strength limits (Griskevičius et al., 2017). The development of chemical container products using 3D printing filaments obtained a process that was inexpensive, had more comprehensive functions, and made it possible to select the appropriate material for a particular role (Gordeev, 2016).

AFO products with PP materials that are mass-produced are often not following the foot anatomy of CP children in Indonesia. The main drawback of AFO products that are widely circulated is the design requirement for the different characteristics of each CP child. In addition to mass-produced AFO products, AFO products with PP materials can be produced in a customized manner, however, it requires a production time of 3 weeks from the casting process to the finished product and requires high costs (Banga et al., 2016). Therefore, it is necessary to innovate in designing AFO to be produced in a customized manner through the application of AM. AFO customization designs made with the application of AM using 3D printing. The deformity rate of conventional AFO is higher when its mechanical properties come from existing materials compared to mechanical properties supplied from ABS materials (Aydin et al., 2018). AFO with PLA filament material has a significant degree of stiffness and gait speed in joint kinematics and musculotendon function during undisturbed gait (Choi, et al, 2017). The application of 3D printing with fiber fabric lamination makes it possible to speed up the production of AFO products at a lower price.

The material requirements for AFO products must be easily adapted to the anatomy of the foot and have high resistance. To support the use of AFO with high resistance, the 3D printing filament is coated with a layer of fiber fabric in the form of carbon fabric and texalium fabric. Carbon fabric is a fiber with a diameter of about 5-10 micrometers and consists mostly of carbon atoms and has the advantages of high stiffness, high tensile strength, and low thermal expansion. Texalium is a fiber based on fiberglass and an aluminum coating on the surface which has the advantage of being tightly woven, impermeable, and soft at a lower cost.

The material requirements for AFO products are needed to determine the characteristics and properties of the materials being assessed, including tensile tests and impact tests. A tensile test is carried out according to ASTM D638-14 to determine the resistance of the material. An impact test is carried out to determine the notch sensitivity of the material according to ASTM D256. Tensile and impact tests were used to determine the characteristics of 3D printing filament as a substitute for PP in AFO products.

II. RESEARCH METHOD

This stage aims to identify the use of PP materials used for conventional AFO products. The material is used as an AFO product because PP has the characteristics of being strong and easy to manage. The PP material in AFO products has the characteristics of a strong material, the material is not easily deformed. Characteristics and properties of mechanical and physical properties based on data on AFO products with PP materials from the paper Patient Specific Ankle-Foot Orthoses Using Rapid Prototyping by Constantinos Mavroidis, et al in 2011. These data are used as a reference to determine the properties of AFO materials.

The characteristics of the 3D printing filament material were obtained from the results of observation and literacy. PLA 3D printing filament material has the advantages of being easy to print, inexpensive, and applicable to a wide variety of applications. ABS has the advantage of being tough, impact resistant, and used to print parts. PETG has the advantages of an easy printing process, provides good coating adhesion, chemical resistance, and does not smell. PC has the advantages of being resistant to high temperatures, easy to bend, and impact resistance. The characteristics and properties of the 3D printing filament material are used as a reference in research.

Mechanical and physical characteristics of carbon fabric and texalium fabric from observations and literacy. Carbon fabric is a fiber with a diameter of about 5-10 micrometers and consists of carbon atoms and has the advantages of high stiffness, high tensile strength, and low thermal expansion. Texalium is a fiber based on fiberglass and an aluminum coating on the surface which has the advantage of being tightly woven, impermeable, and soft at a lower cost. The characteristics and properties of carbon fabric and texalium fabric are used as a reference in research.

Manufacture of 3D printing filament materials into specimens. The process of making specimens is carried out in 5 stages, namely the process of designing specimens according to ASTM D638 and ASTM D256 standards using CAD software. Then the CAD model is saved as a 3D model with the .STL file format and the slicing stage are converted into a 2D thin layer using the Slic3r software. The printing process is through a 3D printing machine. Post-process on the specimen to improve the surface of the final product. and giving a layer of fabric fiber to the specimen.

This study used an experimental method which was analyzed using a three-way ANOVA. The treatment factors in this study were lamination, type of filament, and thickness. Lamination refers to Do, et al (2018), filament type refers to Gordeev (2019) and thickness refers to Shahar, et al (2019).

The goal of this study is to produce an alternative material to replace polypropylene in customized AFO products using 3D printing filaments coated with fiber fabric that suits the needs and characteristics of CP children.

III. RESULT AND DISCUSSION

Identification of the Use of PP Thermoplastic Materials in AFO Products

The characteristics of AFO products which are divided into several types. AFO is shaped like a leg with the main function as a limb strengthener which serves to correct the feet in children with cerebral palsy. This tool is made of polyethylene and polypropylene as described in Table 1.

PP material is widely used in PLS AFO products because it has flexible and useful material characteristics for AFO users for walking activities. Flexibility and support in the PP material are a requirement to absorb pressure between the heel and AFO.

Table 1. AFO Characteristic

Type	Characteristic	Material
Standart (Solid Ankle) AFO	No movement in the legs	Polyethylene
Posterior Leaf Spring (PLS) AFO	Limits and resists plantar flexion and dorsiflexion to several degrees provides support to the posterior heel extending to the calf band	Polypropylene
Ground Reaction (GRAFO) AFO	Almost the Same as Solid AFO on the leg but has an anterior shin pad	Polyethylene

Table 2. Polypropylene Mechanical Properties

Description	Polypropilene
Tensile Strength (MPa)	31 – 37.2
Impact Strength (J/m)	21

Mechanical Properties of PP Thermoplastic Materials in AFO Products

The results of the properties of mechanical and physical properties based on AFO products with PP materials from Patient Specific Ankle-Foot Orthoses Using Rapid Prototyping by Constantinos Mavroidis et al., (2011).

Table 2 shown the mecanical properties of PP material obtained a tensile strength of 31-37.2 MPa, and an impact vstrength of 21 J/m.

Identification of Factors Influencing Tensile and Impact Tests

There are 3 treatment factors carried out in this study. Identification of factors that influence the tensile and impact tests can be shown in Table 3.

Design of 3 treatment factors used in coconut water composite research. Do, et al (2014) lamination treatment factors affect the results of the tensile test. The temperature treatment factors used in this study are carbon fabric and texalium fabric. In Gordeev's research (2016) the treatment factor for the type of filament produces different mechanical and physical characteristics. The types of filaments used in this study were PLA, ABS, PETG and PC. Research by Shahar et al (2019) states that the thickness used in AFO is in the range of 2-4 mm depending on the user's weight. The thickness treatment factors in this study were 1.5 mm, 2 mm, 3 mm and 4 mm.

Manufacture of Test Specimens

This process consists of several stages as follows:

1. The specimen design process according to ASTM D638 and ASTM D256 standards uses CAD software. Figure 1 shows the design process carried out using CAD software in the form of the Autodesk Inventor application. This process is carried out to determine the dimensions of the tensile and impact test specimens in accordance with the ASTM D638 type IV standard with various thickness sizes

Table 3. Tensile Test Result

Treatment Factor	Factor Code	Parameter	Reference
Laminate	A1	*Carbon fabric*	Do et al., 2014
	A2	*Texalium fabric*	
Types of 3D *printing filaments*	B1	PLA	Gordev, 2016
	B2	ABS	
	B3	PETG	
	B4	PC	
Thickness	C1	1.5mm	Shahar et al., 2019
	C2	2mm	
	C3	3mm	
	C4	4mm	

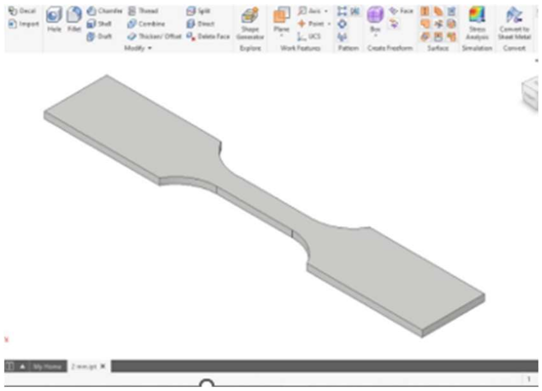

Figure 1. Making Specimen Design

that adjust to the treatment factor and ASTM D256 with the notch v shape.

CAD models saved as .STL files were converted into 2D thin layers using Cura software. After the specimen design is done, the next process is saving the CAD design model as a file in .STL format so that it is processed in the cura software to function as specimen slicing on a 3D printing machine.

2. The printing process through a FDM 3D printing machine. The printing process using a 3D printing machine is carried out according to the slicing projection, where the specimen is placed horizontally to reduce the potential for excessive use of supports and maximize the density between molten lang filaments. The printing process requires a production time of 18-50 minutes for each specimen by adjusting the thickness treatment level to 1.5-4 mm.
3. Post-process on the specimen to improve the surface of the final product. After the specimens have been printed, the next process is post-processing for each specimen, where

Figure 2. Specimen Layering Process

the surface of the specimen is smoothed using sandpaper with a grit level of 60 to facilitate the application of additives in the coating process using fiber fabric.

4. Giving a layer of fiber fabric on specimen
   The process of coating fiber fabric on specimens of 3D printing filament material shown in Figure 2.

Fiber fabric coating process is carried out on both sides of the specimen, each side is given an additive in the form of resin mixed using a catalyst with a composition of 40:1. The additive is applied on one side using a brush and dried first for 10-15 minutes then affixed with fiber fabric and then left for 45-60 minutes until it sticks together. After gluing, the outer layer of the fiber fabric is given an additive as an outer layer and then left for 4-6 hours, then the same process is carried out on the reverse side. The coating process ends with post-processing of the surface and sides of the specimen using sandpaper with 200 grit for neat and smooth specimen results.

Table 4. Tensile Test Result

Lamination	3D *Printing* Filament	Thickness (mm)	Specimen Tensile (MPa)					Average (MPa)
			1	2	3	4	5	
Carbon Fabric	PLA	1,5	248,97	255,65	254,33	258,08	243,88	252,18
		2	263,57	258,31	262,53	252,94	265,08	260,48
		3	273,66	264,26	272,07	274,03	270,02	270,80
		4	284,67	284,40	288,69	277,37	286,00	284,22
	ABS	1,5	198,40	182,33	197,42	188,31	196,21	192,53
		2	201,03	199,54	198,03	204,07	200,25	200,58
		3	214,40	221,42	206,07	215,44	209,53	213,37
		4	221,02	232,31	227,95	234,00	226,74	228,40
	PETG	1,5	224,76	220,00	217,33	211,39	209,69	216,63
		2	221,53	226,07	234,52	222,00	231,02	227,02
		3	237,88	232,06	241,04	230,65	228,07	233,94
		4	251,66	244,26	252,00	259,52	247,38	250,96
	PC	1,5	266,53	271,22	276,67	267,09	274,00	271,10
		2	274,52	279,90	287,35	277,64	281,05	280,09
		3	292,19	286,04	280,00	294,33	295,63	289,63
		4	293,04	308,20	294,42	302,30	307,36	301,06
Texalium Fabric	PLA	1,5	141,23	129,88	146,77	132,58	134,97	137,08
		2	147,04	144,00	138,57	149,16	140,11	143,77
		3	162,75	151,84	147,63	142,31	154,68	151,84
		4	169,74	157,95	161,71	154,77	155,00	159,83
	ABS	1,5	102,42	115,97	111,00	119,40	106,13	110,98
		2	114,68	121,33	124,78	115,16	109,87	117,16
		3	127,44	123,49	119,44	127,65	123,85	124,37
		4	126,08	133,87	135,33	129,49	139,47	132,84
	PETG	1,5	123,49	118,00	126,76	131,44	124,49	124,83
		2	119,47	128,72	135,93	126,57	129,88	128,11
		3	132,50	141,82	129,76	133,00	136,83	134,78
		4	149,79	140,73	138,98	141,78	151,75	144,60
	PC	1,5	148,77	150,00	140,86	155,73	158,45	150,76
		2	152,04	155,60	158,92	148,97	162,36	155,57
		3	157,88	162,35	162,56	168,78	167,54	163,82
		4	174,06	176,12	170,00	179,43	168,02	173,52

Properties and Characteristics of layered 3D Printing Filaments

Tensile testing of 3D printing filaments using the ASTM D638 standard. The dimensions of the tensile test use the ASTM D638 type 4.

Table 4 shown calculation obtained the highest stress value of the specimen treated with carbon fabric lamination, 3D printing PC filament type, and a thickness of 4 mm with a stress value of 301.064 MPa. The lowest stress value of the specimen was treated with texalium fabric lamination, 3D printing filament type ABS and a thickness of 1.5 mm with a stress value of 110.98 MPa.

Tensile Test Stress Normality Test

Tensile test stress normality test. The normality test is used to determine the tensile test stress data for each treatment which is normally distributed. The normality test in this discussion is carried out using the Kolmogorof-Smirnov test.

The tensile stress values obtained from each treatment are normally distributed. The tensile

Table 5. Normality Test

Lamination	3D Printing Filament	Thickness (mm)	P-Value	P coefficient	Normality
Carbon fabric	PLA	1,5	0,15	0,56	Normal
		2	0,17	0,56	Normal
		3	0,21	0,56	Normal
		4	0,15	0,56	Normal
	ABS	1,5	0,2	0,56	Normal
		2	0,22	0,56	Normal
		3	0,16	0,56	Normal
		4	0,14	0,56	Normal
	PETG	1,5	0,2	0,56	Normal
		2	0,21	0,56	Normal
		3	0,24	0,56	Normal
		4	0,23	0,56	Normal
	PC	1,5	0,22	0,56	Normal
		2	0,22	0,56	Normal
		3	0,18	0,56	Normal
		4	0,23	0,56	Normal
Texalium fabric	PLA	1,5	0,22	0,56	Normal
		2	0,19	0,56	Normal
		3	0,16	0,56	Normal
		4	0,22	0,56	Normal
	ABS	1,5	0,16	0,56	Normal
		2	0,23	0,56	Normal
		3	0,17	0,56	Normal
		4	0,14	0,56	Normal
	PETG	1,5	0,15	0,56	Normal
		2	0,18	0,56	Normal
		3	0,25	0,56	Normal
		4	0,29	0,56	Normal
	PC	1,5	0,14	0,56	Normal
		2	0,15	0,56	Normal
		3	0,21	0,56	Normal
		4	0,18	0,56	Normal

value is declared normal when P-value is smaller than the P coefficient.

Homogenity Test

Homogeneity test was carried out using the Bartlett method. The Bartlett method is used to test samples from populations with the same variance. The Bartlett method is used to test sample groups of more than 2 shown in Table 6.

Table 6. Homogenity Test

Repetition	df = (n-1)	Df S^2	logS^2	df logS^2
1	31	113838	3,564	110,513
2	31	113938	3,565	110,524
3	31	115328	3,571	110,688
4	31	113563	3,563	110.48
5	31	115687	3,571	110.73
Total	**155**	**572353**	**17,836**	**552,935**

The homogeneity test obtained the tensile stress value of each group of homogeneous specimens. The Tensile value is said to be homogeneous because the calculated Chi squared is smaller than the table Chi squared.

ANOVA Test

ANOVA testing of tensile test stress data. ANOVA test was carried out to determine the interaction and independent factors that have a significant effect on the tensile stress value. The ANOVA test was carried out after the tensile stress data was declared to be normally distributed and homogeneous. In this study the value of α = 0.05 with a 95% level of confidence.

Tensile stress ANOVA using SPSS software in Table 7, with a significant level of α = 0.05 and a confidence level of 95% on the effect of the lamination factor, 3D printing filament type and thickness resulted that there were 5 factors used in the study which were stated to be significant and 2 factors are not significant. The factor is declared significant if Fcount is greater than Ftable and the significant value is 0.0001 less than the α value.

Table 7. ANOVA Using SPSS

Tests of Between-Subjects Effects

Dependent Variable: Tegangan

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	568419.345[a]	31	18336.108	594.691	.000
Intercept	6058660.839	1	6058660.839	196499.093	.000
Laminasi	461779.270	1	461779.270	14976.776	.000
Filamen	80117.040	3	26705.680	866.139	.000
Ketebalan	16761.291	3	5587.097	181.205	.000
Laminasi * Filamen	8943.038	3	2981.013	96.682	.000
Laminasi * Ketebalan	667.871	3	222.624	7.220	.000
Filamen * Ketebalan	61.693	9	6.855	.222	.991
Laminasi * Filamen * Ketebalan	89.142	9	9.905	.321	.967
Error	3946.627	128	30.833		
Total	6631026.810	160			
Corrected Total	572365.971	159			

a. R Squared = .993 (Adjusted R Squared = .991)

Table 8. Impact Test Result

Filament	Specimen					Average (J/m)
	1	2	3	4	5	
PLA	31,7	33,4	30,7	32,8	30,2	31.76
ABS	24,6	23,1	24,8	25,4	22,8	24,14
PETG	14,4	16,7	14,7	15,2	14,2	15.04
PC	40,4	41.8	40,7	41,1	39,4	40,68

Table 9. Impact Test Result

Description	Polypropylene	PLA with fiber fabric	ABS with fiber fabric	PETG with fiber fabric	PC with fiber fabric
Tensile Stress (MPa)	31–37.2	207.53	165.03	182.61	223,19
Impact Value (J/m)	21	31.76	24,14	15.04	40,68

Table 10. Impact Test Result

Description	*Polypropylene*	PLA	ABS	PETG	PC
Product price (Rupiah)	1,000,000	680,000	560,000	680,000	800,000

Impact Testing Using ASTM D256

Testing the 3D printing filament impact using the ASTM D256 test standard to determine the material ability to absorb energy until the material experiences plastic deformation is shown in Figure 4.

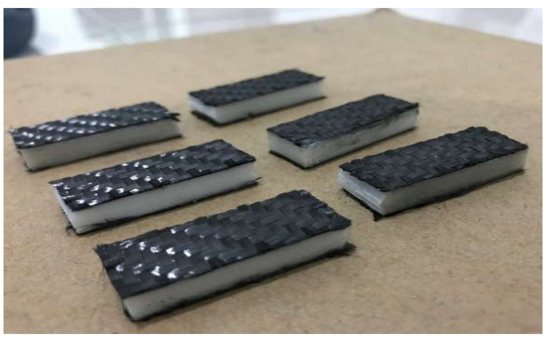

Figure 4. Impact Test Result Specimen

Impact test results are obtained from the energy value through Izod testing utensil. The results of the calculation of the impact price show that the PLA filament has an average impact value of 31.76 J/m, the ABS filament has an average impact value of 24.14 J/m, the PETG filament has an average impact value of 15.04 J/m and the PC filament has an average impact value average impact 40.68 J/m.

Comparative of PP Materials and 3D Printing Filaments

A comparative analysis of PP and 3D printing filaments was carried out to compare the properties of PP and the properties of 3D printing filaments as shown in Table 9.

The tensile stress value of PP and the impact value of PP are 31-37.2 MPa 7-21 J/m. While the results of the 3D printing filament research found that PLA 3D printing filaments were 207.53 MPa, ABS filaments were 165.03 MPa, PETG filaments were 182.61 MPa and PC filaments were 223.19 MPa. The result of 3D printing filament tension is greater than the PP material tension value. Nastiti (2009) states that stress is the maximum ability of a material to withstand loads. Shows that 3D printing filaments can withstand greater loads than PP materials.

Impact test showed that the impact value of the 3D printing PLA filament material was 31.76 J/m, ABS 24.14 J/m, PETG 15.04 J/m and PC 40 J/m. Handoyo (2013) states impact testing is to determine the toughness or brittleness of materials against sudden loads. Shows that PLA, ABS, and PC filaments have toughness compared.

The price for AFO products in Table 5.2, PLA filament material is Rp. 680,000, ABS Rp. 560,000, PLA of Rp. 680,000 and PLA of Rp. 800,000. Gordeev (2016) stated that the use of 3D printing filaments resulted in a process that was inexpensive, had wider functions and made it possible to select the appropriate material for a particular function. Shows that filament has a lower price compared to PP material AFO products.

IV. CONCLUSION

This study aim to produce an alternative material to replace polypropylene in customized AFO products using 3D printing filaments coated with fiber fabric that suits the needs and characteristics of CP children. This study show that fiber-coated 3D printing filaments have a higher tensile stress value than PP material, but the impact value on the type of PETG filament material is lower than PP material. The optimal composition of the specimen manufacturing process is found in the lamination treatment of carbon fabric, PC filament type, and a thickness of 4 mm with a stress value of 301.064 MPa and an impact value of 40.68 J/m. Filament materials have lower prices than PP materials with ABS having the lowest price and PC having the highest price.

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