Experimental evaluation of finding optimum process parameters for ABS material using C300D printer

Poondla Vishnu Vikas

Abstract— The goal of this project is to quantitatively analyze the potential of fused deposition modeling to fully evolve into a rapid manufacturing tool. The project objective is to develop an understanding of the dependence of the mechanical properties of FDM parts on raster orientation and to assess whether these parts are capable of maintaining their integrity while under service loading. The study utilizes the insights provided by previous researchers and further examines the effect of fiber orientation on a variety of important mechanical properties of ABS components fabricated by fused deposition modelling.

Index Terms— ABS,Fill density,Instron,Orientation,Print speed,Print temperature,Raster angle,Specimen.

◆

INTRODUCTION

Fused deposition modeling (FDM) is one such layered manufacturing technology that produces parts with complex geometries by the layering of extruded materials, such as durable acrylonitrile butadiene styrene (ABS) plastic[5] . In this process, the build material is initially in the raw form of a flexible filament. The feedstock filament is then partially melted and extruded though a heated nozzle within a temperature controlled build environment.

The material is extruded in a thin layer onto the previously built model layer on the build platform in the form of a prescribed two-dimensional (x-y) layer pattern[2] . The deposited material cools, solidifies, and bonds with adjoining material. After an entire layer is deposited, the build platform moves downward along the z-axis by an increment equal to the filament height (layer thickness) and the next layer is printed on the top of it.

If the model requires structural support for any overhanging geometry, a second nozzle simultaneously extrudes layers of a water soluble support material in this same manner[17]. Once the build process is completed, the support material is dissolved and the FDM part can be viewed as a laminate composite structure with vertically stacked layers of bonded fibers or rasters[24] . Consequently, the mechanical properties of FDM parts are not solely controlled by the build material of the original filament, but are also significantly influenced by a directionally-dependent production process that fabricates components with anisotropic characteristics associated with it.

This study uses FDM build recommendations provided in previous work, as well as the defined machine default values, in order to focus analysis specifically on the significant issue of fiber or raster orientation, i.e. the direction of the polymer beads (roads) relative to the loading direction of the part[10]. Tensile, compressive, flexural, impact, and fatigue strength properties of FDM specimens are examined, evaluated, and placed in context in comparison with the properties of injection molded ABS parts[12].

In recent years, layered manufacturing processes have begun to progress from rapid prototyping techniques towards rapid manufacturing methods, where the objective is now to produce finished components for potential end use in a product. LM is especially promising for the fabrication of specific need, low volume products such as replacement parts for larger systems. This trend accentuates the need, however, for a thorough understanding of the associated mechanical properties and the resulting behaviour of parts produced by layered methods[15]. Not only must the base material be durable, but the mechanical properties of the layered components must be sufficient to meet in-service loading and operational requirements, and be reasonably comparable to parts produced by more traditional manufacturing techniques.

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Physical properties of ABS such as amorphous, very commonly used thermo-plastic polymer. It's density is 1.04g/cc with a melt flow of 21.3g/10min. This study was focused on the application of Taguchi optimization technique to find the optimum levels of process parameters used in injection of thin-shell plastic components for orthose part by improving the warpage problem with shrinkage variation. L27 and L9 Taguchi orthogonal design are used for different mold flow analyses. Proved that materials can be produced with more flexibility by the usage of composites. Coming to mechanical properties Rockwell hardness value ranges from 103-112 , tensile strength average of 44MPa and break elongation of 24.3%. These tests were carried out by Iron/Copper + ABS composites involving metal content upto 40% by volume with controlled centrifugal mixing.

By using grey – fuzzy logic , instead of optimising all the parameters can be merged into single major factor. Flexural modulus comes around 2.3GPa with an yield strength of 68.9MPa. Izod impact test gave an average value of 2.8J/cm. Major electrical properties include arc resistance of 120sec, with Comparative Tracking Index of 600V. These parameters include built style, raster angle, raster width, mold and metal temperature, filling time and pressure.

Upon comparing the values with temperature , loss modulus value is directly proportional whereas storage modulus and viscosity varies inversely. Hot Wire Ignition and High Amp Arc Ignition are 15sec and 120 arcs respectively. Thermal properties comprises of maximum service temperature 88.7^{0}C, having a softening point of 212^{0}F. In this study, frequency sweep is performed in DMA 2980 equipment to determine modulus, damping and viscosity values.

Thermo gravimetric analysis was analysed with no weight loss . Moulded samples shown higher surface finish inducing the detailed comparative study of fdm products. Flammability UL94 Horizontal burning(HB). The chemical composition consists of 15-35% acrylonitrile, 5-30% butadiene, 40-60% styrene. This technique is also used for layer thickness, orientation, tensile, compression, flexural and impact tests.

A number of research worksbased on various optimization techniques were reviewed including RSM, Taguchi method, full factorial, gray relational, fractional factorial, ANN, fuzzy logic and GA. A review of research work on various optimization techniques indicated that there were successful industrial applications of Taguchi method, RSM, GA and ANN. Analysis of 3-D printed parts mainly takes the comparison between Fused Deposition Modelling and Injection moulding. Surface roughness, dimensional accuracy, contour width, material behaviour and build time are also measured.

Graphical analysis was carefully done by using pygc chromatography technique for different samples categorized. The temperature under which the rate in TGA decreases fastest is relative to the period during which the number of the peak is the most in the PyGC chromatogram. This includes flexural, compressive, tensile and surface finish analysis. The first two gave positive results for FDM technique for 0.2mm layer thickness but the last two showed the greater values for moulded parts. Flame retardant properties of PC/ABS blends with different amount of flame retardants are significantly different.

Inter layer cooling influences the quasi – static mechanical properties of FDM – ABS components by changing the number of parts that are built at a time through optical microscopy. Thermo Gravimetric Analysis showed the optimum values for both the samples. To overcome this issue composites of ABS are being used nowadays. Uniaxial test samples are built considering the build orientation and the number of parts in the envelope, in order to influence this inter-layer cooling time. Tensile tests are performed and the fracture surfaces are investigated using digital microscopy.

This paper deals for increasing strength within less time for 3D printed parts. It was observed that layer height influence majorly for ultimate tensile strength and printing time, whereas, extrusion temperature influences much for the elastic modulus.These composites mainly include iron filled in the layers of ABS matrix which gives stiffness and hence high tensile characteristics. Preliminary studies on the influence of build orientation were carried out by varying the y-axis orientation of the specimen and confirm that model built using y –axis orientation of 45^0 yields better mechanical properties.

ABS manufactured gears were tested for different tooth loads as they are durable against flame, air, ultraviolet lights and holding lower moisture than PA66 GFR 30 materials, the usage of them brings an advantage in many industrial areas. Additive materials should be added to PC/ABS materials for rising durability . Loss modulus increased upon increasing the temperature but the storage modulus as well as viscosity showed inversely proportional results. However PC and ABS polymers combine each other, the PC/ABS blends have suitable mechanical properties for gear applications in the industrial areas

In this paper, a method for the creation of lightweight, metal cellular structures was presented utilizing the capabilities of indirect 3D printing and traditional casting techniques. Vacuum casting processes , topology optimisation techniques under certain load conditions are also investigated. Excellent impact resistance, good machinability, excellent aesthetic qualities, easy to paint and glue, good strength and stiffness with low cost are some of the characteristics of ABS. Progress towards exploring the use of metal casting into 3D printed sand molds for creating cellular materials and sandwich panels.

Anisotropic behaviour of ABS specimens are significantly influenced by the orientation of the layered rasters and the resulting directionality of the polymer molecules. Raster orientation with analytical and computational models propagated fatigue strength. It's applications in various industries include food handling and equipment, Aircraft-Aerospace-Defense, oil & gas, Medical technology materials, Material handling, Alternative energy. Leads to rapid protyping techniques to rapid manufacturing methods.

The values obtained of glass transition temperature in DSC and the decomposition temperature in TGA clearly indicates that the thermal stability of the composite is not affected by the increase in CS concentration.The other fields which use ABS are Machined prototypes, Structural components, Support blocks, Housings and covers.

ABS can be vacuum metalized and electro-plated paved the way for its extensive use in automobiles.

Points drawn from this study mainly include the increase in the current density increases the temperature of the electrolyte, and thus causes peeling of the electroplated layers. Various process parameters comprises of Layer thickness, Air gap, Raster angle, Build orientation, Road width and Number of contours. *For electroplating, the plastic model needs to be made electrically conductive in order for the electroplating process to work, and in this paper an attempt has been made to show and understand the development of*
electroplating setup for plating ABS plastics.

This study found that increasing the extrusion temperature reduced the extruded filament diameter through the extruder die. The superficial print quality of the recycled filament was of a similar consistency as commercial filaments, as confirmed by surface roughness analysis. With these key parameters Storage modulus, Loss modulus as well as Mechanical damping were calculated. Examining the potential of using 100% recycled ABS to form filaments for use in Fused Deposition Modelling (FDM) 3D printing.

The initial state of material in Rapid Prototyping technologies can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. Layer thickness of 0.3302mm, zero air gap, raster angle of 0.0^0, build orientation of 0.0^0, road width of 0.4572mm with 10 contours maximises the mechanical damping, storage & loss modulus. Contribution are presented basic information about common and advanced materials used for realization of products by Fused Deposition Modeling Rapid Prototyping technology application.

Raster angle is the parameter which has the most significant effect on flexural strength of PC-ABS component made by FDM process, when compared with the other parameters taken into account. The material usage by the FDM machine can be optimized with the help of these parameter settings. Using FDM900mc machine, Raster angle of 45°/45° yields higher flexural strength when compared with other parameters considered. Similarly, for surface roughness, contour style is the most significant parameter, where the triple contour style gives better surface finish.

Reprocessing and thermo oxidation of ABS have a much more severe effect on impact properties and elongation-at-break than tensile properties. As the reprocessing and thermo-oxidation conditions become more and more severe, degradation of the polybutadiene phase seems to become progressively more significant. Thus, it may be deduced that the changes occurring during service life of ABS are part of the life cycle which mostly affect its further recycling possibilities and performance in second-market applications.

The estimated value of the Axons is always greater than the value of the time recording process and measurement of the mass printing results. Printing process using ABS was 2661 seconds, which was faster than using the PLA was 2808 seconds. For the material consumption, show that the average mass of ABS was 7,33 grams compared with using PLA was 8,17 grams.

In this research the FDM process parameters air gap and number of contours show a significant effect on the storage modulus and loss modulus. A gradual increase in storage modulus has been observed with the decrease in air gap and increase in the number of contours. The most influential parameters were statistically obtained through the analysis of variance (ANOVA) technique. The optimal parameters for maximum dynamic mechanical properties were found to be layer thickness of 0.3302 mm, air gap of 0.00 mm, raster angle of 0.0^0, build orientation of 0.0^0, road width of 0.4572 mm, and 10 contours.

This paper mainly focusses on air gap parameter has been proved statistically to influence the surface finish of FDM built parts, combined with layer thickness at (0.254 mm) and raster width at (0.508 mm). By applying negative air gap at (-0.01), the beads of ABS M-30i overlapped and the voids between the built beads were filled, this resulted in a smooth surface construction and a lower Ra value compared with other built parts with default settings. *ABS- M30i biomedical material was used in this research work to build parts.*

Analysis of Shear strength and stiffness between layers were higher than those measured between roads. Because of the non-isotropic behavior of the parts made by FDM process, the strength of local area in the part depends on the raster direction. Using the Design of Experiment (DOE) approach the typical tensile strength ranged between 65 percent and 72 percent of the strength of injection molded ABS P400.

Metal additive manufacturing can eliminate the welding and machining of multiple units by building designs in a singular part. Applications such as Metal 3D printing, with its advanced metals offering, is best utilized in highly complex and involved designs. It can significantly reduce the assembly of designs by consolidating parts into a single build were discussed practically. Traditionally machined metals, such as stainless steel and titanium, have been created as powdered metals for manufacturing with Direct Metal Laser Sintering (DMLS) 3D printing.

Evaluation of the fraction of stored energy delivered to a victim load during an ESD event, the next experiment will attempt to quantify the amount of available charge participating during an ESD event from a dielectric surface. The powder would coat the charged sections of the inner sphere while leaving the uncharged sections clean were discussed. Investigated the validity of the plasma kinetic model by measuring the current profile received by a realistic victim load in order to quantify the energy deposition.

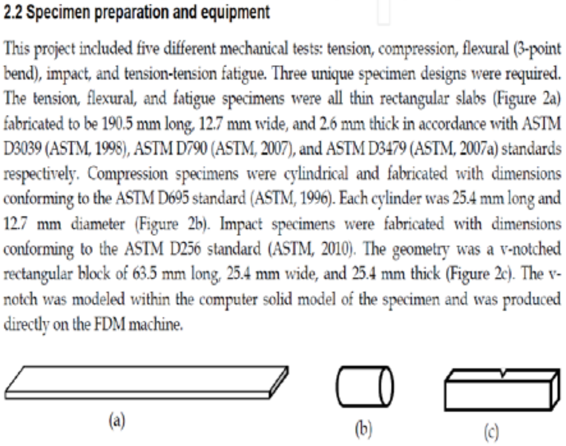
The analysis that has been run in this study is Taguchi Analysis and continued with ANOVA optimization methods. The results for both methods used have been analyzed.

The Signal to Noise (S/N) ratio and Analysis of Variance (ANOVA) method is applied in identifying the best parameter settings and to find the influence of these parameters on warpage issue. In this study, Packing Time is found to be the most significant parameter, regardless of the material used.

Experimental Procedure

Identifying the Design of Experiment for 4 factors and 3 levels. L9 orthogonal Design of experiment is appropriate to determine the necessary optimum parameters[21]. Constant Bed temperature of 95-110 degC. Extruder temperature varies from 220-250 degC. Parameters to be considered for printing test specimens are Layer Height , Fill Density , Print Temperature and Print Speed.

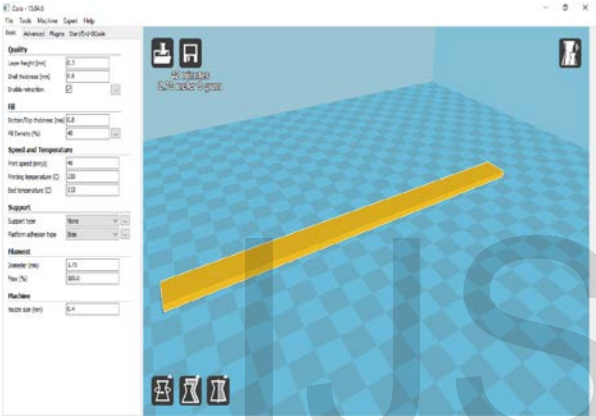
All the test specimen dimensions as per ASTM standards mentioned in research papers which we can get during Literature Survey[8].Making the 3D CAD models for tensile test and flexural test , the specimen is thin rectangular slab of 190.5mm long, 12.7mm wide, 2.6mm thick. For compression test the specimen is cylindrical of 25.4mm long, 12.7mm diameter whereas for Impact testing the specimen is 63.5mm long, 25.4mm wide, 25.4mm thick.The V notch was modelled within the computer model.



2.2 Specimen preparation and equipment

This project included five different mechanical tests: tension, compression, flexural (3-point bend), impact, and tension-tension fatigue. Three unique specimen designs were required. The tension, flexural, and fatigue specimens were all thin rectangular slabs (Figure 2a) fabricated to be 190.5 mm long, 12.7 mm wide, and 2.6 mm thick in accordance with ASTM D3039 (ASTM, 1998), ASTM D790 (ASTM, 2007), and ASTM D3479 (ASTM, 2007a) standards respectively. Compression specimens were cylindrical and fabricated with dimensions conforming to the ASTM D695 standard (ASTM, 1996). Each cylinder was 25.4 mm long and 12.7 mm diameter (Figure 2b). Impact specimens were fabricated with dimensions conforming to the ASTM D256 standard (ASTM, 2010). The geometry was a v-notched rectangular block of 63.5 mm long, 25.4 mm wide, and 25.4 mm thick (Figure 2c). The v-notch was modeled within the computer solid model of the specimen and was produced directly on the FDM machine.

Fig. shows ASTM standards.



Figures showing Cura model , brim and specimens.

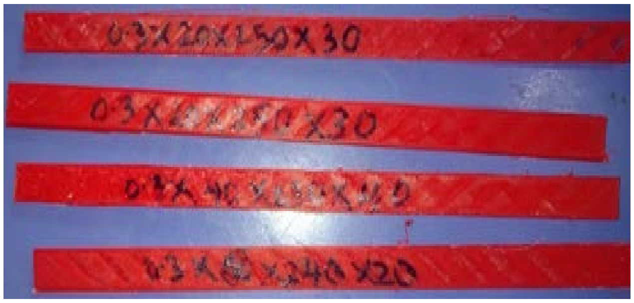


Fig. all the required test specimens

	Parameter	1	2	3
F1	LayerHeight (mm)	0.1	0.2	0.3
F2	Fill Density (%)	20	40	60
F3	Print Temperature (deg C)	230	240	250
F4	Print Speed (mm/s)	20	30	40

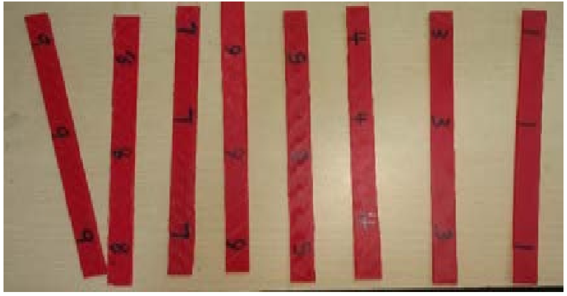
Tensile Test

Institute	VIT Vellore
Laboratory Name	ADV Materials Processing and testing lab
Operator ID	POONDLA VISHNU VIKAS
Rate 1	1.000mm/min
Humidity(%)	60.00
Temperature (deg C)	25.00

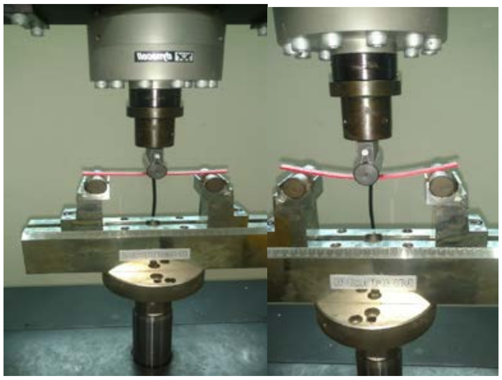
Brim: 20 mm prevents warpage , makes easy - to remove specimen. These Tensile test Specimens were given for testing under INSTRON.The strain rate given to the machine for carrying out Tensile test varies from 1 mm per min.

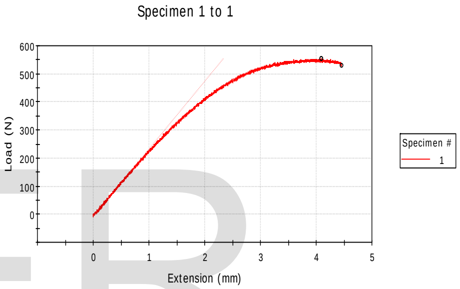
FLEXURAL TEST

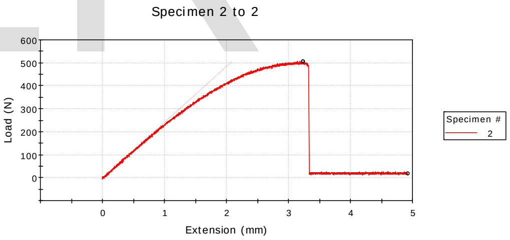
Flexural test is also performed on the same machine INSTRON as it is a Universal Testing Machine, only the equipment must be changed.Strain rate given is raised to 3 mm/min rather than 1 mm/min for tensile test because load acting is much slower ,as it consumes lot of time.As ABS material is ductile, the specimens are tested and removed before they touch the extreme edge whereas for brittle materials , test will be performed upto breakage of specimen**.**

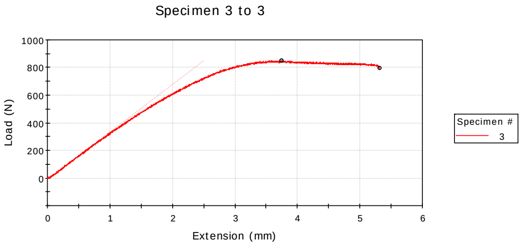


To determine the most influencing factor among these parameters ANOVA can be performed in Excel.As 4 factors are mapped to Flexural and Tensile tests, One way ANOVA is feasible.With this analysis , we can calculate individually by taking single parameter with Flexural and Tensile strengths as output.We need to give this as Null and alternative hypothesis respectively by level of significance.Finally , with the help of F-test we can accept or reject accordingly.





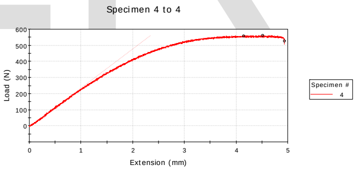


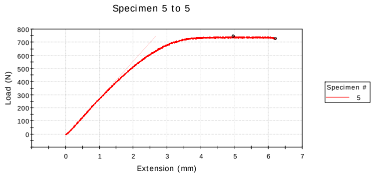


	Specimen label	Tensile strain at Maximum Load (%)	Load at Break (Standard) (kN)	Tensile stress at Break (Standard) (MPa)	Comment
1	001	3.14472	0.53	18.44	1
2	001	2.48362	0.02	0.60	2
3	001	2.87771	0.80	27.69	3
4	001	3.46834	0.53	18.34	4
5	001	3.81820	0.73	25.23	5
6	001	2.50370	-0.01	-0.23	6
7	001	2.49019	0.01	0.28	7
8	001	2.18110	0.02	0.78	8
9	001	5.77505	0.52	18.00	9
Maximum		5.77505	0.80	27.69	
Mean		3.19363	0.35	12.13	
Minimum		2.18110	-0.01	-0.23	

	Final Area at Area Reduction (mm^2)	Initial Area at Area Reduction (mm^2)	Reduction of Area at Area Reduction (%)	True strain at Maximum Load (mm/mm)
1	110.00000	28.80000	-281.94444	0.03096
2	110.00000	28.80000	-281.94444	0.02453
3	110.00000	28.80000	-281.94444	0.02837
4	110.00000	28.80000	-281.94444	0.03410
5	110.00000	28.80000	-281.94444	0.03747
6	110.00000	28.80000	-281.94444	0.02473
7	110.00000	28.80000	-281.94444	0.02460
8	110.00000	28.80000	-281.94444	0.02158
9	110.00000	28.80000	-281.94444	0.05614
Maximum	110.00000	28.80000	-281.94444	0.05614
Mean	110.00000	28.80000	-281.94444	0.03139
Minimum	110.00000	28.80000	-281.94444	0.02158

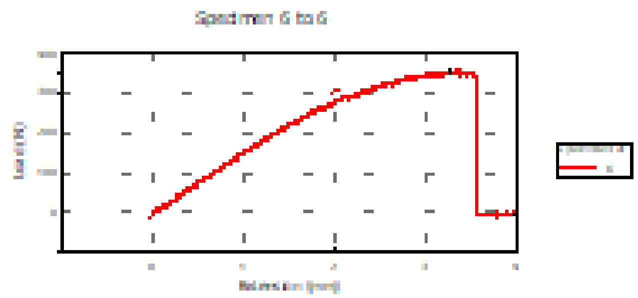
Maximum Load (N)	UTS (GPa)	Modulus (Automatic Young's) (MPa)	Tensile strain at Break (Standard) (%)
553.39336	0.019	1087.287	3.425
506.21033	0.018	1100.611	3.782
848.92511	0.029	1553.785	4.088
560.71281	0.019	1092.843	3.799
746.34552	0.026	1289.997	4.767
357.84245	0.012	702.571	3.061
243.78300	0.008	523.889	3.054
82.08752	0.003	198.599	2.882
528.68128	0.018	744.946	6.024
848.92511	0.029	1553.785	6.024
491.99793	0.017	921.614	3.876

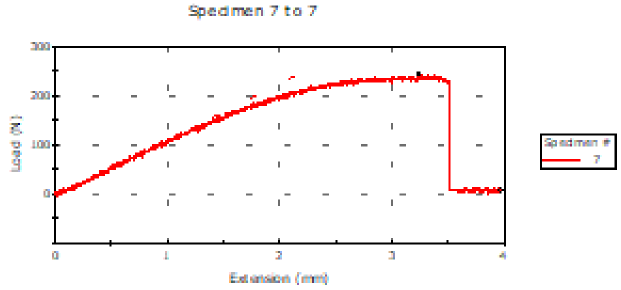


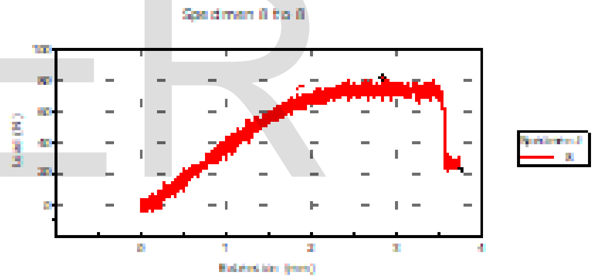


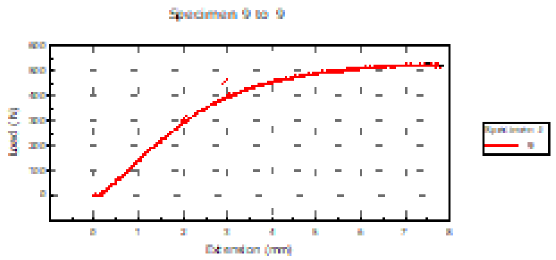
	True stress at Maximum Load (Pa)	% Elong. at Tensile Strength at Non-proportional Elongation (Standard) (%)	% Elongation at Break at Non-proportional Elongation (Standard) (%)	Elong. at Tensile Strength at Non-proportional Elongation (Standard) (mm)
1	19819306.46215	0.79115	1.16606	1.02850
2	18013286.31383	0.35582	3.70943	0.46256
3	30324817.92006	1.69130	1.95366	2.19870
4	20144452.29614	1.06045	1.53078	1.37859
5	26904253.02695	2.27704	2.43626	2.96015
6	12736172.33938	2.50370	3.06098	3.25482
7	8675474.23836	2.49019	3.05357	3.23725
8	2912427.95108	2.18110	2.88185	2.83543
9	19417114.23999	2.59295	2.70912	3.37083
Maximum	30324817.92006	2.59295	3.70943	3.37083
Mean	17660811.64311	1.77152	2.50019	2.30298
Minimum	2912427.95108	0.35582	1.16606	0.46256

	Elongation at Break at Non-proportional Elongation (Standard) (mm)
1	1.51588
2	4.82226
3	2.53976
4	1.99001
5	3.16714
6	3.97927
7	3.96964
8	3.74641
9	3.52185
Maximum	4.82226
Mean	3.25025
Minimum	1.51588

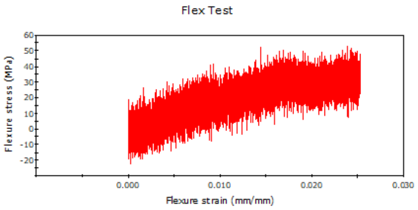








Flexural test graphical view


Flex Test
Flexure stress (MPa)
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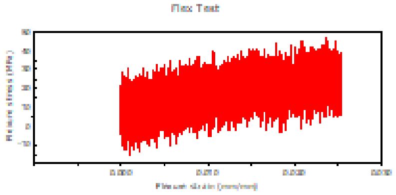
Flexure strain (mm/mm)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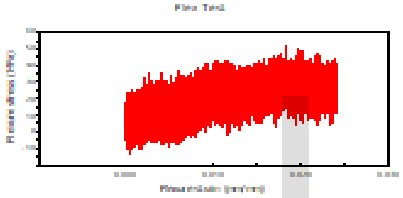
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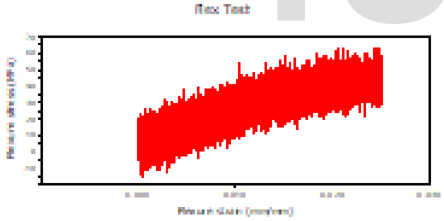
Flexure strain (mm/mm)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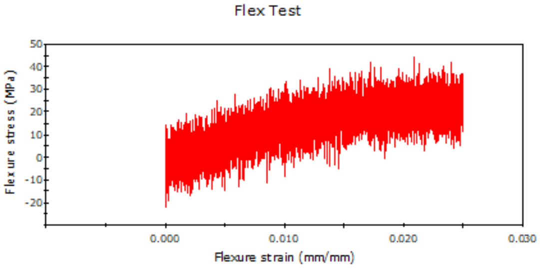
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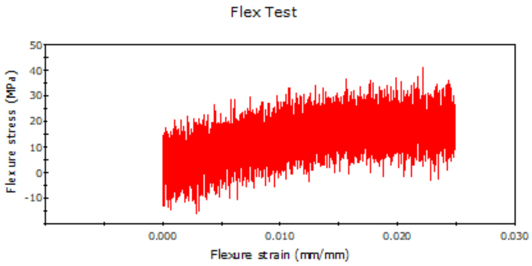
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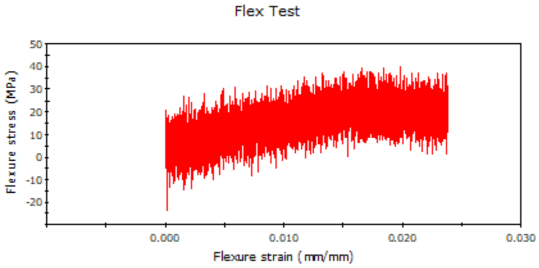
Flexure strain (mm/mm)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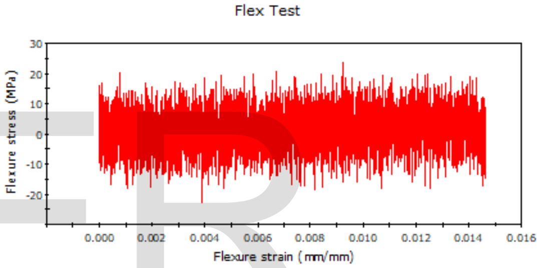
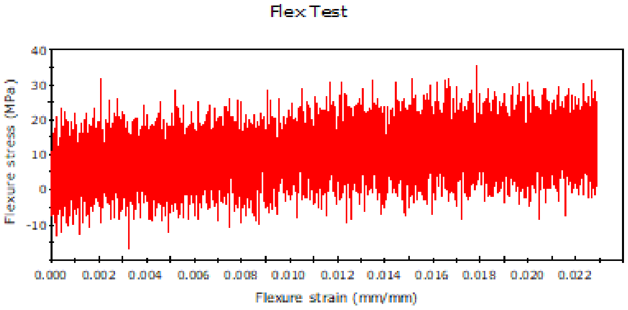
0.030
Flexure strain (mm/mm)


Flex Test
Flexure stress (MPa)
30
20
10
0
-10
-20
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
Flexure strain (mm/mm)


Flex Test
Flexure stress (MPa)
40
30
20
10
0
-10
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
Flexure strain (mm/mm)

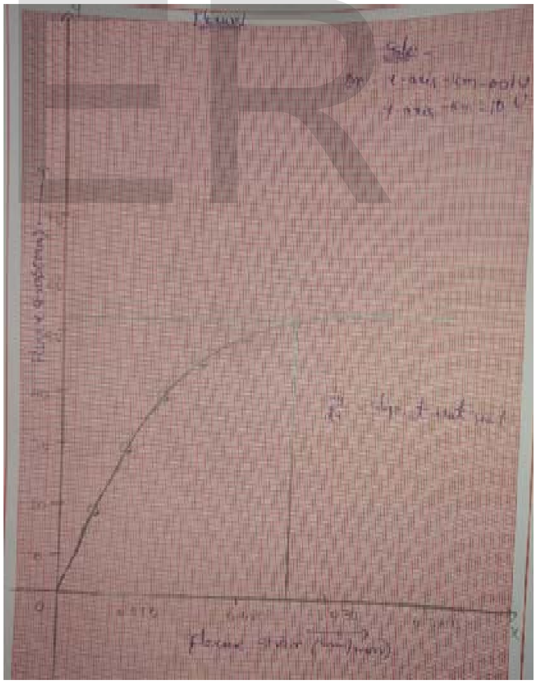
	Specimen label	Comment	Maximum Load (N)	Maximum Flexure stress (MPa)
1	001	1	20.12	52.72128
2	001	2	18.11	47.47259
3	001	3	19.80	51.89336
4	001	4	24.28	63.64045
5	001	5	17.02	44.59830
6	001	6	15.61	40.91172
7	001	7	15.27	40.02131
8	001	8	9.20	24.10339
9	001	9	13.52	35.42870
Mean			16.99	44.53235

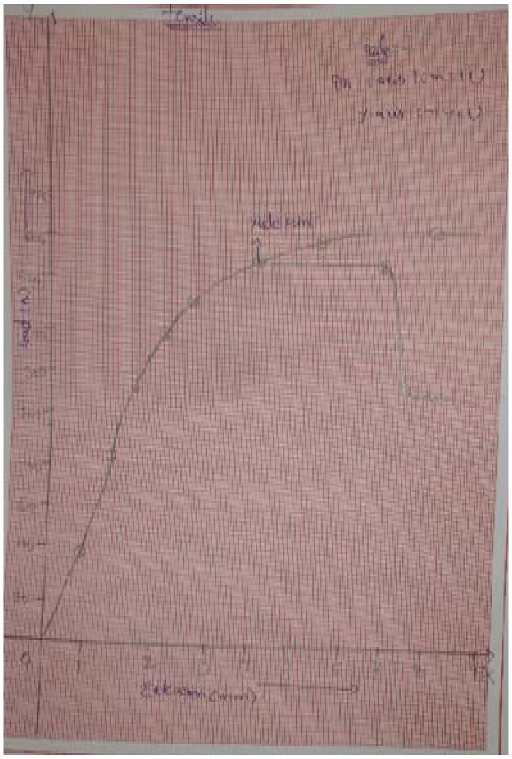
	Maximum Flexure extension (mm)	Modulus (Automatic) (MPa)	Flexure stress at Yield (Zero Slope) (MPa)	Flexure strain at Maximum Flexure stress (mm/mm)
1	34.454	2958.56891	52.23703	0.02389
2	34.038	1288.24971	47.47259	0.02360
3	26.376	2889.10635	42.59880	0.01829
4	35.384	2286.26171	-----	0.02453
5	30.004	2259.28119	44.59830	0.02080
6	32.007	1572.84093	28.83659	0.02219
7	28.521	1706.83431	31.57029	0.01977
8	13.344	26426.09084	20.82295	0.00925
9	25.770	8639.73124	31.64839	0.01787
Mean	28.877	5558.55169	37.47312	0.02002

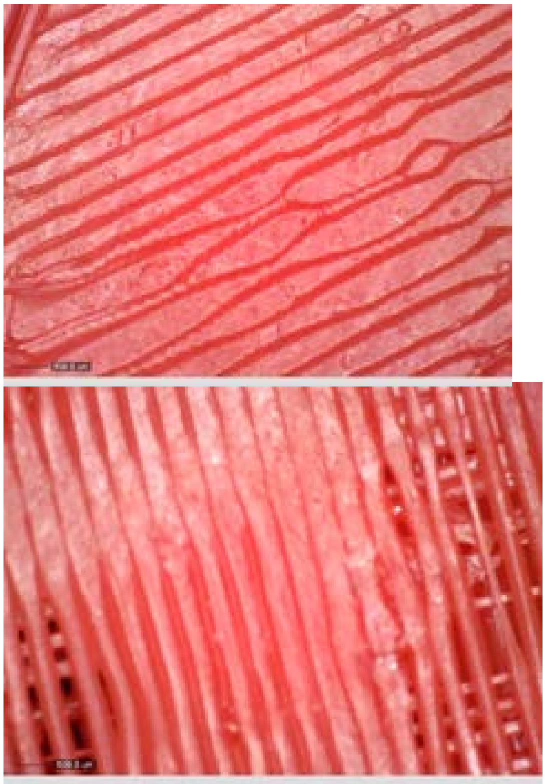
To determine the most influencing factor among these parameters ANOVA can be performed in Excel.As 4 factors are mapped to Flexural and Tensile tests, One way ANOVA is feasible.With this analysis , we can calculate individually by taking single parameter with Flexural and Tensile strengths as output.We need to give this as Null and alternative hypothesis respectively by level of significance.Finally , with the help of F-test we can accept or reject accordingly.

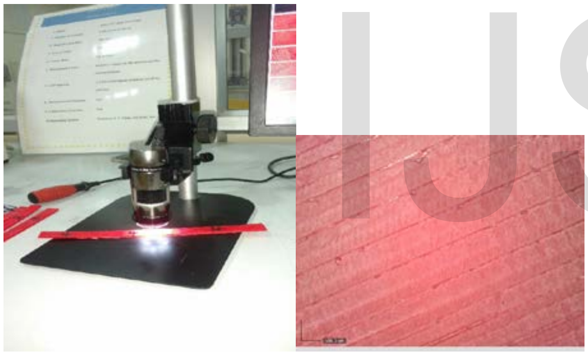
Micro – structure observation:

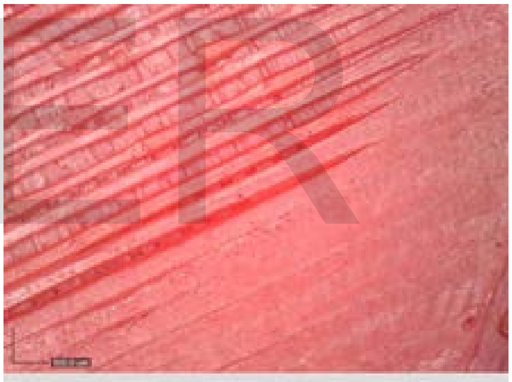
With the help of Dynolite under 75 – 80 x magnification , the micro structures of surface roughness , alignment of layers after performing Tensile and Flexural tests can be found.
For Specimens 3 and 4 of maximum Tensile and Flexural strengths, the layers are closely packed even after tested under heavy loads.But for Specimen 8 which got minimum Tensile and Flexural strengths, the layers are disturbed drastically resulting in heavy gaps between them .This induced several defects in the specimen and finally lead to Failure.

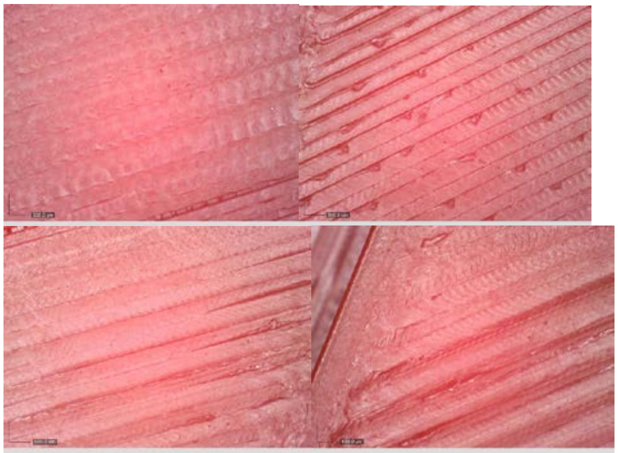


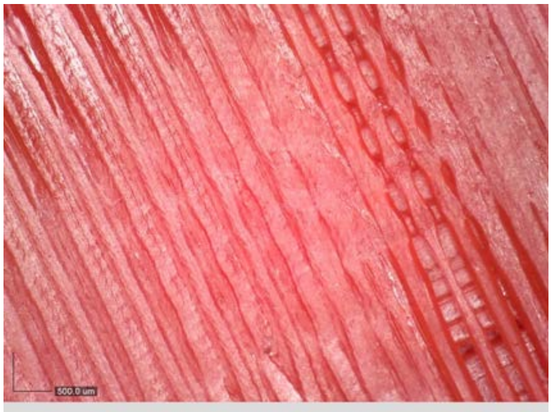


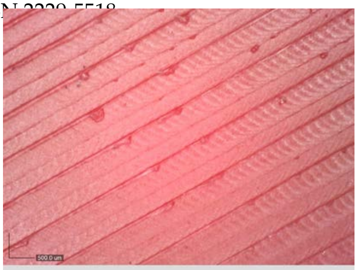


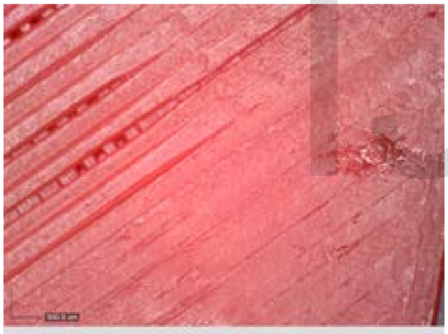


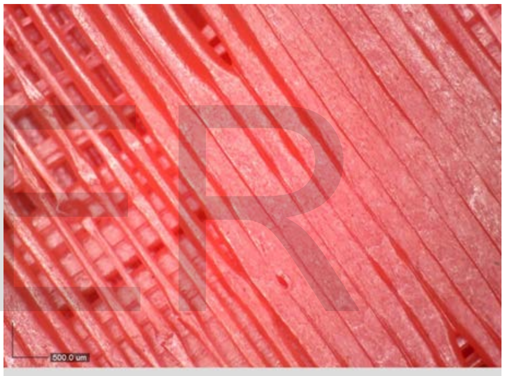


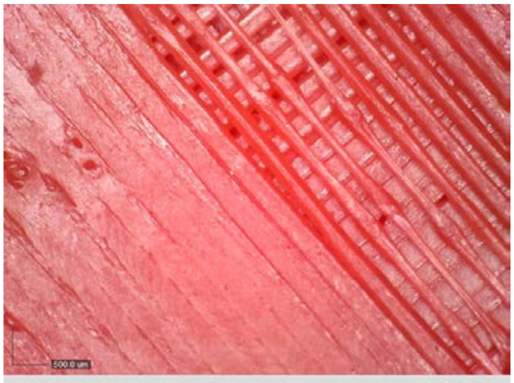



500.0 um









Conclusion

Hence from the above results specimen 3 showed maximum UTS of 0.029 Gpa , and specimen 8 showed least UTS of

0.003 Gpa,specimen 4 showed maximum Flexure stress of 63.64045 Mpa , and specimen 8 showed least Flexure stress of 24.10339 Mpa.Layer height,Fill density,Print temperature,Print speed for specimen 3 are 0.1mm, 60%, 250degC, 40mm/s and for specimen 8 are 0.3mm, 40%,230degC,40mm/s. Similarly for specimen 4 they are 0.2mm, 20%, 240degC, 40mm/s whereas for sample 8 they are 0.3mm, 40%, 230degC, 40mm/s.

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REFERENCES

[1] Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part Hasan Oktem , Tuncay Erzurumlu , Ibrahim Uzman H. Oktem et al. / Materials and Design 28 (2007) 1271–1278.

[2] Thermo-mechanical properties of a highly filled polymeric composites for Fused Deposition Modeling M. Nikzad, S.H. Masood , I. Sbarski M. Nikzad et al. / Materials and Design 32 (2011) 3448–3456.

[3] Application of grey-fuzzy logic on the optimal process design of an injection-molded part with a thin shell feature Ko-Ta Chiang , Fu-Ping Chang K.-T. Chiang, F.-P. Chang / International Communications in Heat and Mass Transfer 33 (2006) 94–101.

[4] Dynamic Mechanical Properties of ABS Material Processed by Fused Deposition Modelling Adhiyamaan Arivazhagan , S.H. Masood Adhiyamaan Arivazhagan, S.H. Masood / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 3, May-Jun 2012, pp.2009-2014.

[5] Analysis of mechanical behavior of 3D printed ABS parts by experiments Divyathej M V, Varun M, Rajeev P International Journal of Scientific & Engineering Research, Volume 7, Issue 3, March-2016 116 ISSN 2229-5518.

[6] Optimization of fused deposition modeling process parameters a review of current research and future prospects Omar A. Mohamed • Syed H. Masood • Jahar L. BhowmikAdv. Manuf. (2015) 3:42–53 DOI 10.1007/s40436-014-0097-7.

[7] Research on Thermostability of Flame-retardant PC / ABS-Blends with PyGC Jian Zhang*Jian Zhang / Procedia Engineering 135 (2016) 83 – 89.*

[8] Influence of inter-layer cooling time on the quasi-static properties of ABS components produced via Fused Deposition Modelling M. Faes ,a, E. Ferrarisa, D. Moensa *M. Faes et al. / Procedia CIRP 42 (2016) 748 – 753.*

[9] INFLUENCE OF PROCESS PARAMETERS ON THE MECHANICAL BEHAVIOUR AND PROCESSING TIME OF 3D PRINTING Ramu Murugan1, Mitilesh R.N2, Sarat Singamneni3 International Journal of Modern Manufacturing Technologies ISSN 2067–3604, Vol. X, No. 1 / 2018.

[10] The load capacity of PC/ABS spur gears and investigation of gear damage R. Yakut, H. Düzcükoğlu, M.T. Demirci Volume 40 Issue 1 November 2009 Pages 41-46.

[11] LIGHTWEIGHT METAL CELLULAR STRUCTURES VIA INDIRECT 3D PRINTING AND CASTING Nicholas A. Meisel, Christopher B. Williams, Alan Druschitz REVIEWED, Accepted August 16, 2012.

[12] Anisotropic Mechanical Properties of ABS Parts Fabricated by Fused Deposition Modelling Constance Ziemian1, Mala Sharma1 and Sophia Ziemian2.

[13] Studies on thermal, electrical and flame properties of surface modified cenosphere filled ABS composites Jaymin R. Desai & S. C. Shit & S. K. Jain Int J Plast Technol (December 2014) 18(3):390–396 DOI 10.1007/s12588-014-9099-3.

[14] DEVELOPMENT OF ELECTROPLATING SETUP FOR PLATING ABS PLASTICS MITHUN V KULKARNI ELANGOVAN K HEMACHANDRA REDDY K *i-manager's Journal on Mechanical Engineering, Vol. 2 l No. 3 l May - July 2012.*

[15] EcoPrinting: Investigating the use of 100% recycled Acrylonitrile Butadiene Styrene (ABS) for Additive Manufacturing Mazher Iqbal Mohammed, Anirudra Das, Eli Gomez-Kervin, Daniel Wilson, Ian Gibson .

[16] Basic and Advanced Materials for Fused Deposition Modeling Rapid Prototyping Technology Ludmila Novakova-Marcincinova, Ivan Kuric Manuf. and Ind. Eng., 11(1), 2012, ISSN 1338-6549.

[17] Investigation on the effect of Fused Deposition Modeling Process Parameters onFlexural and Surface Roughness properties of PC-ABS blend S. Manikandan A.S. Seshan Kumar, C. Sharma .

[18] Study on the Recycling of ABS Resins: Simulation of Reprocessing and Thermo-oxidation Dariuosh Salari and

Heidar Ranjbar Iranian Polymer Journal / Volume 17 Number 8 (2008).

[19] PROCESSING AND MATERIALS EFFICIENCY IN FUSED DEPOSITION MODELING: A COMPARATIVE STUDY ON PARTS MAKING USING ABS AND PLA POLYMERS Yopi Yusuf Tanoto1, Juliana Anggono1,2 and Wesley Budiman1,2 VOL. 12, NO. 23, DECEMBER2017 ISSN 1819-6608.

[20] Effect of Process Parameters on Dynamic Mechanical Performance of FDM PC/ABS Printed Parts Through Design of Experiment Omar Ahmed Mohamed, Syed Hasan Masood, Jahar Lal Bhowmik, Mostafa Nikzad, and Jalal Azadmanjiri 2922—Volume 25(7) July 2016.

[21] Parameter Optimization of ABS-M30i Parts Produced by Fused Deposition Modeling for Minimum Surface Roughness S.Dinesh KumarȦ , V.Nirmal KannanḂ and G.SankaranarayananĊ *International Journal of Current Engineering and Technology, Special Issue-3, (April 2014).*

[22] Material Characterization of Fused Deposition Modeling (FDM) ABS by Designed Experiments Michael Montero1, Shad Roundy1, Dan Odell1, Sung-Hoon Ahn2 and Paul K. Wright1.

[23] 3D PRINTING MATERIALS: CHOOSING THE RIGHT MATERIAL FOR YOUR APPLICATION .

[24] Experimental Validation of the Plasma Kinetic Model Webb, Matthew David Hardy, Zachary Kenneth 2018-03-14.

[25] Warpage Analysis on Thin Plate by Taguchi Method and Analysis of Variance (ANOVA) for PC, PC/ABS and ABS Materials S. M. Nasir, N. A. Shuaib, Z. Shayfull, M. Fathullah, R. Hamidon *International Review of Mechanical Engineering (I.RE.M.E.), Vol. 5, N. 6 September 2011.*