Experimental Investigations And Mechanical Properties on 3d Printing Parts of Thermoplastic Polyurethane Material

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Abstract- *The intention of this examine changed into to research the applicability of thermoplastic polyurethane (TPU) as a 3-d printing cloth and the situations associated with the usage of TPU as non-public defensive equipment. The tensile strength, surprise absorption, and compressibility had been evaluated for unique infill and thickness condition. Three-dimensional (three-D) printing is a good and sustainable era beneficial in diverse production fields. The intention of this have a look at changed into to analyze the applicability of thermoplastic polyurethane (TPU) as a three-D printing fabric and the situations associated with the usage of TPU as nonpublic defensive equipment. The tensile strength, surprise absorption, and compressibility had been evaluated for specific infill and thickness situations. A boom withinside the infill price brought about a boom withinside the tensile strength, irrespective of the pattern thickness. Similarly, the compression strength elevated because the infill elevated. Both the surprise absorption and compression residences elevated because the thickness reduced below same infill situations. The real surprise absorption check records had been as compared to the effects of structural analyses, which showed the capacity for predicting effect deformation thru the evaluation of the tensile traits and the primary residences of a three-D published fabric.*

I. INTRODUCTION

1.1 Additive manufacturing

There area unit several terms like Additive producing, 3D printing, fast prototyping and additional, that area unit accustomed describe specifc technologies. though they're not exactly synonyms, all of them area unit associated with a specifc method of product producing. Nowadays, we tend to area unit still accustomed build machines and components from solid blocks of staple, then machining away material till desired form if non inheritable.

Since then, AM trade developed quickly and is these days price many billions of greenbacks on the market. Its significance cannot be stressed out enough, and generally we tend to don't seem to be paying the maximum amount attention to AM as we should always. It takes plenty of your time to completely notice, however massive distinction in terms of components production AM will cause.

The future of AM market continues to be to unfold, however statistics area unit showing that AM machines will be used additional in production method - particularly with the continual trend of rising materials convenience, development of recent materials or deduction of all key electronic and mechanical components. With this trend, demand for AM specialists is probably going to extend. Since then, AM industry developed rapidly and is today worth several billions of dollars on the market. Its significance can't be stressed out enough, and sometimes we are not paying as much attention to AM as we should. It takes a lot of time to fully realize, how big difference in terms of parts production AM can cause.

The future of AM market is still to unfold, but statistics are showing that AM machines willbe used more in production process - especially with the continuous trend of improving materials availability, development of new materials or price reduction of all key electronic and mechanical parts. With this trend, demand for AM specialists is likely to increase.

1.2 Polymers:

The word “Polymer” comes from 2 Greek words, ‘Poly’ which means several (numerous) and ‘Mer’ which suggests units. In basic terms, a chemical compound could be a long-chain molecule that's composed of an oversized range of repetition units of identical structure. These identical structures, we tend to perceive as a unit created from 2 or additional molecules, be part of along to make an extended chain. merely expressed, a chemical compound could be a long-chain molecule that's composed of an oversized range of repetition units of identical structure. Those monomers will be easy — simply Associate in Nursing atom or 2 or 3 — or they

may be difficult ringed structures containing a dozen or additional atoms.
The first classification of polymers is predicated on their supply of origin, Let’s take a glance.

a) Natural polymers

The easiest thanks to classify polymers is their supply of origin. Natural polymers area unit polymers that occur in nature and area unit existing in natural sources like plants and animals. Some common examples area unit Proteins (which area unit found in humans and animals alike), polyose and Starch (which area unit found in plants) or Rubber (which we tend to harvest from the latex of a tropical plant).

b) artificial polymers

Synthetic polymers area unit polymers that humans will by artificial means create/synthesize during a research lab. These area unit commercially created by industries for human wants. Some ordinarily created polymers that we tend to use day to day area unit polythene (a factory-made plastic that we tend to use in packaging) or Nylon Fibers (commonly employed in our garments, fishing nets etc.)

c) Semi-Synthetic polymers

Semi-Synthetic polymers area unit polymers obtained by creating modification in natural polymers by artificial means during a research lab. These polymers shaped by chemical process (in a controlled environment) and area unit of business importance. Example: processed Rubber (Sulphur is employed in cross bonding the chemical compound chains found in natural rubber) cellulose ester (rayon) etc.

1.3.2 Classification supported Structure of Polymers

a) Linear polymers:

These polymers area unit similar in structure to an extended open chain that identical links connected to every different. The monomers in these area unit coupled along to make an extended chain. These polymers have high melting points and area unit of upper density. a standard example of this is often PVC (Poly-vinyl chloride). This chemical compound is essentially used for creating electrical cables and pipes.

b) Branch chain polymers:

As the title describes, the structure of those polymers is like branches originating every which way points from one linear chain. Monomers be part of along to make an extendd open chain with some branched chains of various lengths. As a results of these branches, the polymers don't seem to be closely packed along. they're of denseness having low melting points. Low-density polyethene (LDPE) employed in plastic baggage and general purpose containers could be a common example

c) Cross linked or Network polymers:

In this form of polymers, monomers area unit coupled along to make a three-dimensional network. The monomers contain robust valency bonds as they're composed of bi-functional and tri-functional in nature. These polymers area unit brittle and arduous. Ex:- Bakelite (used in electrical insulators), alkali etc.

1.3.3 supported Mode of chemical change

Polymerization is that the method by that chemical compound molecules area unit reacted along during a chemical process to make a chemical compound chain (or three-dimensional networks).

1.3.4 supported the sort of polymerisation, polymers will be classified as:

a) Addition polymers:

Thesetype of polymers area unit shaped by the continual addition of chemical compound molecules. The chemical compound is created by polymerisation of monomers with double or triple bonds (unsaturated compounds). Note, during this method, there's no elimination of little molecules like water or alcohol etc (no by-product of the process). Addition polymers continuously have their empirical formulas same as their monomers. Example: alkene n(CH_2=CH_2) to polyethene -(CH_2-CH_2)n-.

b) Condensation polymers:

These polymers area unit shaped by the mixture of monomers, with the elimination of little molecules like water, alcohol etc. The monomers in these kinds of condensation reactions area unit bi-functional or tri-functional in nature. a standard example is that the polymerisation of Hexamethylenediamine and hexanedioic acid. to grant Nylon – sixty six, wherever molecules of water area unit eliminated within the method.

1.3.5 Classification supported Molecular Forces

Intramolecular forces area unit the forces that hold atoms along inside a molecule. In Polymers, robust valency bonds be part of atoms to every different in individual chemical compound molecules. building block forces (between the molecules) attract chemical compound molecules towards one another.

Note that the properties exhibited by solid materials like polymers rely for the most part on the strength of the forces between these molecules. Using this, Polymers will be classified into four types:

a) Elastomers:

Elastomers area unit rubber-like solid polymers, that area unit elastic in nature. once we say elastic, we tend to essentially mean that the chemical compound will be simply stretched by applying a touch force.

The most common example of this could be seen in rubber bands(or hair bands). Applying a touch stress elongates the band. The chemical compound chains area unit control by the weakest building block forces, thence permitting the chemical compound to be stretched. however as you notice removing that stress additionally ends up in the band taking on its original type. This happens as we tend to introduce crosslinks between the chemical compound chains that facilitate it in retracting to its original position, and taking its original type. Our automobile tyres area unit fabricated from processed rubber. this is often once we introduce sulphur to cross bond the chemical compound chains.

b) Thermoplastics:

Thermoplastic chemical compounds area unit long-chain polymers during which inter-molecules forces (Van der Waal's forces) hold the polymer chains along. These polymers once heated area unit softened (thick fluid like) and hardened after they area unit allowed to chill down, forming a tough mass. they are doing not contain any cross bond and may simply be formed by heating and mistreatment moulds. a standard example is cinnamene or PVC (which is employed in creating pipes).

c) Thermosetting:

Thermosetting plastics area unit polymers that area unit semi-fluid in nature with low molecular lots. once heated, they begin cross-linking between chemical compound chairs, thence turning into arduous and infusible. They type a three-dimensional structure on the appliance of warmth. This reaction is irreversible in nature. the foremost common example of a thermoset chemical compound is that of Bakelite, that is employed in creating electrical insulation.

d) Fibres:

In the classification of polymers, these area unit a category of polymers that area unit a thread like in nature, and may simply be plain-woven. they need robust inter-molecules forces between the chains giving them less physical property and high lastingness. The building block forces could also be H bonds or dipole-dipole interaction. Fibres have sharp and high melting points. a standard example is that of Nylon-66, that is employed in carpets and apparels.

II. LITERTURE REVIEW

2.1 Study on fused deposition modelling process and Thermoplastic Polyurethane material

Ziemian and Crawn (2001) distinguished various research endeavors to create "strategies for filling the inside of each layer" … "so as to deliver parts rapidly, that are solid, or that have a decent surface completion". For some modern applications, FDM innovation appropriation is constrained by a limited precision and poor surface unpleasantness.

ISO/TC 261 and ASTM F42, (2013).Joint arrangement for added substance producing gauges improvement. Joint Planning Session. Jerez-Mesa, R., J.A. Travieso-Rodriguez, X. Corbella, R. Busque, and G. Gomez-Gras, (2016). Limited component investigation of the warm conduct of a RepRap 3D printer liquefier. Mechatronics, http://dx.doi.org/10.1016/j.mechatronics.2016.04.007.

Jerez-Mesa, et al. (2016), found that expulsion liquefier controls ordinarily use points of confinement to turn on and off warming components, making "a normal adjusting criticism circle framework". Last part quality in parts created utilizing FDM innovation is profoundly needy upon the nature of between fiber holding inside each layer. Material temperatures are set and balanced by administrators in the construct parameters and constrained by criticism sensors situated in the material liquefier. Savvakis, et al. (2014), tried examples worked as solids utilizing Stratasys fabricate measures that produce parts with fill rates of about 97%. This 3% void is especially huge when endeavoring to assess fiber weld quality as it makes various obscure factors. Another device way factor influencing FDM parts is identified with the sudden corners among line and small curve toward the finish of a street, requiring a sharp vacillation of speed of the spout/print head. This adjustment in speed and course may deliver unfilled territories close to the defining moments and in the meantime, unnecessary filled territory exist in the opposite side of the corner (Jin, et al., 2013). Despite the fact that the main man-made plastic material was presented more than 150 years prior (Parkes, 1865), the plastics business confronted a test as worldwide markets were opening up, to encourage worldwide models.

Lynch et al.., 1995, much of the examination directed in the main decade following stereolithograpy, and even into the 2000s, was focused on the improvement and flawlessness of unique fast prototyping nature. Like conventional prototyping, venture throwing assumed a huge job in this procedure and consequently numerous papers were distributed taking a gander at the precision and pertinence of supplanting the time and expert abilities expected to make the conciliatory examples used to make artistic molds (Atwood, et al., 1996; Lynch, 1995; Mueller, 1992 &1995). Following ten years of innovative work, the materials accessible for quick prototyping/added substance assembling were beginning to improve.

Krutch, Leu et.al.., detailed in 1998, "better mechanical, warm and dimensional properties" with a bed of about all materials. In the same way as other innovation advancements after some time, added substance assembling has had its developing agonies.

As Gershenfeld notes, "similarly likewise with the old centralized servers" and "early massive and costly PC controlled processing gadgets" the first AM frameworks were constrained to institutional associations in light of the huge speculation costs (Gershenfeld, 2012). Ongoing years have seen emotional changes in the expenses of added substance fabricating innovation, "improvements from organizations, for example, 3D Systems, Stratasys, Epilog Laser, and Universal brought the cost" … "down from countless dollars to several thousands, making them alluring to research gatherings" (Gershenfeld, 2012).

2.2 OBJECTIVES OF PRESENT WORK

To explore the effect of liquefier temperature and feed rate on mechanical properties viz. tensile strength, flexural strength and Izod impact strength in 3D printing process using thermoplastic polyurethane filament material.

III. MATERIALS &EXPERIMENTS

3.1 Thermoplastic Polyurethane Samples Fabrication:

Thermoplastic polyurethane (TPU) is unique category of plastic created when a Polyaddition reaction occurs between di isocyanate and one more diols.

For this work, I have taken Thermoplastic Polyurethane (TPU) filament to print the parts.Thedia of wire is1.75mm.By using Fused Deposition Modelling machine, we print the parts as our requirement. For the samples fabrication, we used two parameters like temperature and feed rate. In this parts are prepared in unidirectional way. In this we used 210^0c,220^0c, 230^0c. Feed rate of 15ccgm/hr, 17.5ccgm/hr, 20ccgm/hr. For the TPU material, it have very less melting temperature range. For every components, we used these parameters to prepare the parts.

Table 3.1 Methodology for printing of 3D Parts

SL No	Orientation	Temp	Feed
1	Unidirectional	210^0c	15ccgm/hr
2	Unidirectional	220^0c	17.5ccgm/hr
3	Unidirectional	230^0c	20ccgm/hr

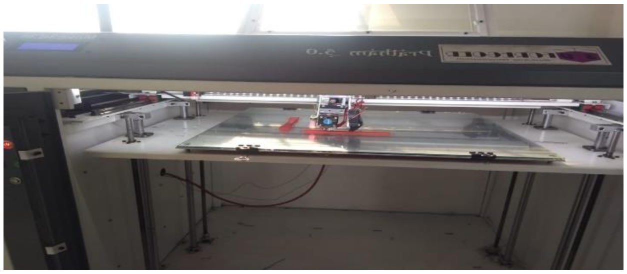


Fig 3.1 Pratham 5.0 3D Printer

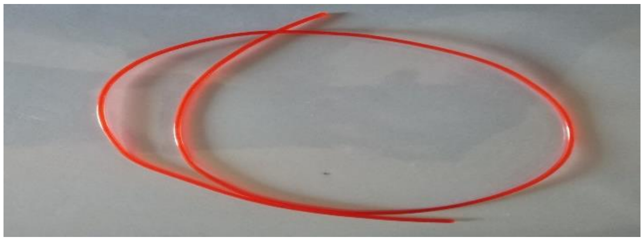


Fig3.2 Thermoplastic Polyurethane Filament(Ø 1.75mm)

3.2 Tensile Strength

The resistance of the material for breaking under tension.

3.2.1 Tensile Specimen:

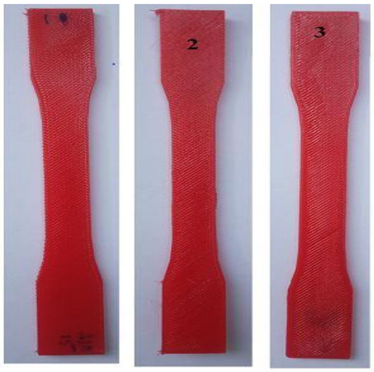


Fig.3.3 3D Printed Tensile Specimens

3.2.2 Experimental Procedure:

To know the tensile strength for the given Thermoplastic polyurethane Sample,we use Universal Testing Machine. The UTM instrument have two jaws. We place our sample in between the two jaws. After fixing the sample inbetween the jaws, we put on the machine. The loads are increased gradually.

TPU tensile tests are carried out on DAK 7200 series universal tensile machine with a maximum loading capacity of 25 KN, which allowed us to obtain more precision given nature of the test material, and the geometry of the test pieces of dimensions **165mm x 19mm x 3.2mm**. which have a small thickness. The tests were carried out at a uniform speed of 1 mm / min with controlled displacement.Elastic tests are utilized to decide how materials will carry on under pressure load. In a basic malleable test, an example is regularly dismantled to its limit to decide a definitive elasticity of the material.

The measure of power (F) connected to the example and the stretching (ΔL) of the example are estimated all through the test. Material properties are regularly communicated as far as stress (power per unit zone, σ) and strain (percent change long, ε). To acquire pressure, the power estimations are partitioned by the example's cross-sectional area ($\sigma = F/A$). Strain estimations are acquired by isolating the adjustment long by the underlying length of the example ($\varepsilon = \Delta L/L$). These qualities are then introduced on a XY plot called a pressure strain bend. Testing and estimating systems differ dependent on the material being tried and its expected application.

3.2.3 About UTM Machine:

Fig3.4 DAK 7200 Series UTM Machine

Tensile test is frequently done at a material testing research facility. The ASTM D638 is among the most widely recognized elastic testing conventions. The ASTM D638 measures plastics tractable properties including extreme rigidity, yield quality, prolongation and Poisson's proportion. The most well-known testing machine utilized in ductile testing is the universal testing machine.

The machine must have the best possible capacities for the test example being tried. At last, the machine must probably precisely and unequivocally measure the check length and powers connected; for example, a huge machine that is intended to gauge long extensions may not work with a fragile material that encounters short lengthening preceding fracturing.

3.3 Flexural Strength (ASTM D790)

Flexural testing is generally used to determine the flexural modulus or flexural strength of the given material. Flexural testing is to determine the bending properties of the given material. To determine the flexural strength of the material,we use 3 point bending test machine. Flexural strength of the composites was determined from the three point bending technique. It can be carried out in the modified UTM machine in accordance with ASTM D790. The specimen rectangular shape with dimensions of **125mm** x **13mm** x **7 mm**.The experiments were conducted at a crosshead speed of 0.5 mm/min. Then flexural strength was caluculated using simple bending moment diagram of simply supported beam at central point load.

Fig3.5 3D Printed Flexural Specimens

Fig 3.6 Process of Flexural Strength testing

3.4 Izod Impact Test: (ASTM D256)

Notched Thermoplastic Polyurethane Izod specimens were used to create notched ASTM D256 Izod specimens. Figureshows the notched bar.

The sample was oriented with the notch perpendicular to the parting line; the top and bottom surfaces were minimally machined to maintain dimensions as well as perpendicularity. The 3D printinted thermoplastic polyurethane specimen. The Izod striker had a 0.66 mm radius and contacted the specimen at a 5° angle. A total of three specimens of each specimen were tested, but the specimen was not broken because of high elastic nature. In this Izod Impact testing,we didn't get any results.

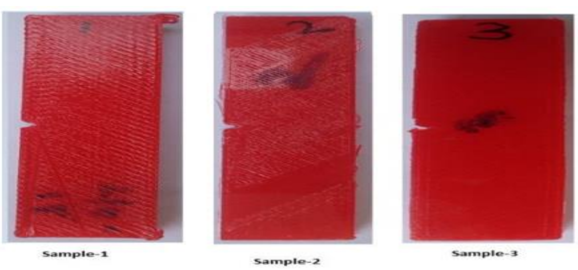


Fig3.7 Izod Impact test Specimens

IV. RESULTS & DISCUSSIONS

4.1 Tensile Strength:

The resistance of the material to breaking under tension.

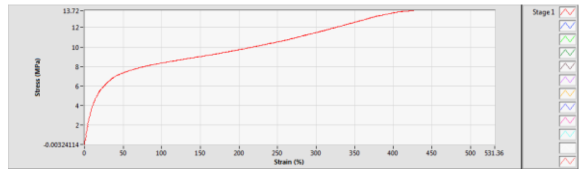
4.1.1 Tensile test Specimen 2 (220^{0}c, 17.5ccgm/hr)

Fig4.1 Tensile Specimen-2 (220^{0}c, 17.5ccgm/hr)

Table 4.1 Results of Specimen-2 (220^{0}c, 17.5ccgm/hr)

Specimen	Date &	Width	Thickness	CSA	Peak Load	TS	Mod@100
Total 1	Time	mm	mm	sq.mm	N	MPa	MPa
1	10/04/19_10:46	14.240	3.250	46.280	634.963	13.720	8.354

Specimen	Mod@200	Mod@300	El@Break	Mod@500	Mod@700	Tensile St	Mod@50
Total 1	MPa	MPa	%	MPa	MPa	kg/sq.cm	MPa
1	9.708	11.470	426.640	0.472	NA	13.720	7.337



Graph 4.1 Stress-Strain Curve for Specimen-2 (220^{0}c, 17.5ccgm/hr)

Table4.2 Methodology for printing of 3D Parts

SL No	Orientation	Temp	Feed
1	Unidirectional	210^{0}c	15ccgm/hr
2	Unidirectional	220^{0}c	17.5ccgm/hr
3	Unidirectional	230^{0}c	20ccgm/hr

The tensile specimens are prepared by Thermoplastic Polyurethane(TPU) filament material. For this tensile specimens, I am varying some parameters like temperature and feed rate.By using the tensile specimen, we have to find the tensile strength. Initially we applied 10KN force to perform tensile strength. Stress values are in Mpa& Strain values are in % of elongation.. In this experiment we get maximum tensile strength of 13.72Mpa to break the given specimen. In this we get elongation break at 426.64%. The graph is plotted between Stress Vs Strain.Stress values are in Mpa& Strain values are in %Values.

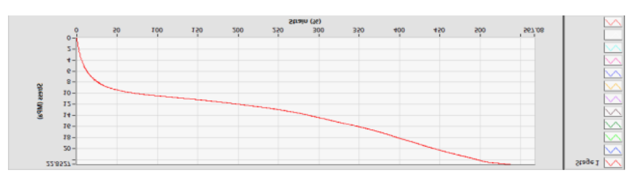
4.1.2 Tensile test Specimen 3 (230^{0}c,20ccgm/hr)

Fig4.2 Tensile Specimen-3 (230^{0}c,20ccgm/hr)

Table 4.3 Results for Specimen-3 (230^{0}c,20ccgm/hr)

Specimen	Date &	Width	Thickness	CSA	Peak Load	TS	Mod@100
Total 1	Time	mm	mm	sq.mm	N	MPa	MPa
2	10/04/19_12:11	13.750	3.110	42.762	977.237	22.853	10.466

Specimen	Mod@200	Mod@300	El@Break	Mod@500	Mod@700	Tensile St	Mod@50
Total 1	MPa	MPa	%	MPa	MPa	kg/sq.cm	MPa
2	11.979	14.443	536.840	22.197	NA	22.853	9.399



Graph 4.2 Stress-Strain Curve for Specimen-3 (230^{0}c,20ccgm/hr)

Table 4.4 Methodology for printing of 3D Parts

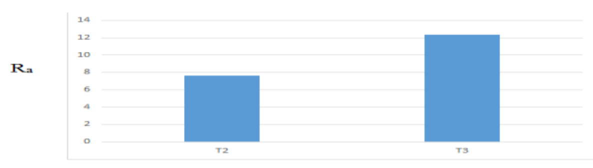
SL No	Orientation	Temp	Feed
1	Unidirectional	210^0c	15ccgm/hr
2	Unidirectional	220^0c	17.5ccgm/hr
3	Unidirectional	230^0c	20ccgm/hr

The tensile specimens are prepared by Thermoplastic Polyurethane(TPU) filament material. For this tensile specimens, I am varying some parameters like temperature and feed rate.By using the tensile specimen, we have to find the tensile strength.. Initially we applied 10KN force to perform tensile strength. Stress values are in Mpa& Strain values are in % of elongation.In this load is converted as stress value & displacement is converted as strain value. In this experiment we get maximum tensile strength of 22.853Mpa to break the given specimen.In this we get elongation break at 536.84%. The graph is plotted between Stress Vs Strain.Stress values are in Mpa& Strain values are in %Values.

Table 4.5 Surface Roughness for Tensile Specimens

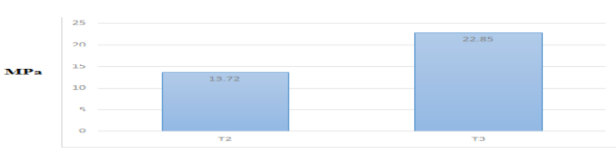
S.No	Specimen	Surface Roughness(R_a)
1	T_2	7.65
2	T_3	12.339

Comparison of Surface roughness for Izod Impact specimens



Graph 4.3 Comparison of Surface roughness for Tensile specimens

Comparison of tensile strength for TPU specimens:



Graph 4.4 Comparison of Tensile Strength for TPU specimens

4.2 Flexural Strength Testing :

The tendency for a material to resist bending.

4.2.1 Flexural test Specimen 1(210^{0}c, 15ccgm/hr):

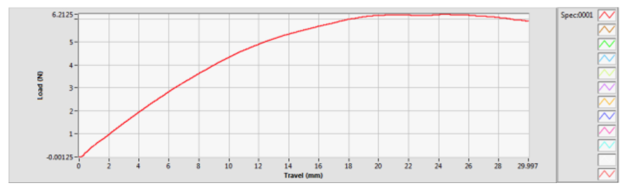
Fig4.3 Flexural Specimen-1 (210^0c,15ccgm/hr)

Table4.6 Results for Specimen-1 (210^0c, 15ccgm/hr)

Specimen	Batch	Date &	Span	Width	Depth	Flextural stress1	Flextural stress2
Total 1	Name	Time	mm	mm	mm	MPa	MPa
Spec:0001	Student	10/04/19_13:32	100.000	12.645	6.165	0.000	0.100

Specimen	Flexural strength	Load@0.75mm	Load@1mm	Load@1.5mm	Load@2mm	Load@2.5mm	Load@1.25mm
Total 1	MPa	N	N	N	N	N	N
Spec:0001	1.939	0.366	0.492	0.735	0.975	1.229	0.623

Specimen	Load@1.75mm	Load@2.25mm	Flextual strain- N	Chord Modulus	Load@1%	Secant Modulus
Total 1	N	N	mm/mm	MPa	N	MPa
Spec:0001	0.851	1.107	0.091	50.000	1.329	41.479



Graph 4.3 Load vs Distance travel

Table4.7 Methodology for printing of 3D Parts

SL No	Orientation	Temp	Feed
1	Unidirectional	210^0c	15ccgm/hr
2	Unidirectional	220^0c	17.5ccgm/hr
3	Unidirectional	230^0c	20ccgm/hr

The flexural specimens are prepared by Thermoplastic Polyurethane(TPU) filament material. For this tensile specimens, I am varying some parameters like temperature and feed rate.By using flexural specimen, we get flexural strength. For this test, initially we given 1KN load to the machine. For this specimen we get flexural strength of 1.939MPa.In this we plot the graph between load vs distance travel of specimen.

4.2.2 Flexural test Specimen 2(220^{0}c, 17.5ccgm/hr):

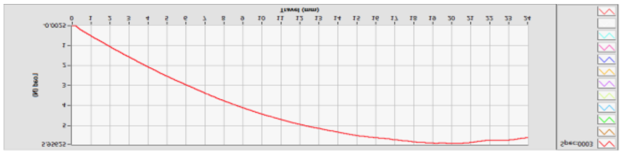
Fig4.4 Flexural Specimen-2 (220^0c, 17.5ccgm/hr)

Table4.8 Results for Specimen-2 (220^0c, 17.5ccgm/hr)

Specimen	Batch	Date &	Span	Width	Depth	Flextural stress1	Flextural stress2
Total 1	Name	Time	mm	mm	mm	MPa	MPa
Spec:0003	Student	10/04/19_14:22	64.000	12.785	5.886	-0.000	0.015

Specimen	Flexural strength	Load@0.75mm	Load@1mm	Load@1.5mm	Load@2mm	Load@2.5mm	Load@1.25mm
Total 1	MPa	N	N	N	N	N	N
Spec:0003	1.291	0.397	0.509	0.777	1.050	1.312	0.649

Specimen	Load@1.75mm	Load@2.25mm	Flextual strain- N	Chord Modulus	Load@1%	Secant Modulus
Total 1	N	N	mm/mm	MPa	N	MPa
Spec:0003	0.914	1.187	0.258	7.500	0.602	13.047



Graph 4.4 Load vs Distance travel

Table 4.9 Methodology for printing of 3D Parts

SL No	Orientation	Temp	Feed
1	Unidirectional	210^0c	15ccgm/hr
2	Unidirectional	220^0c	17.5ccgm/hr
3	Unidirectional	230^0c	20ccgm/hr

The flexural specimens are prepared by Thermoplastic Polyurethane (TPU) filament material. For this tensile specimens, I am varying some parameters like temperature and feed rate.By using flexural specimen, we get flexural strength. For this test, initially we given 1KN load to the machine. For this specimen we get flexural strength of 1.291MPa.In this we plot the graph between load vs distance travel of specimen.

4.2.3 Flexural test Specimen 3(230^0c,20ccgm/hr):

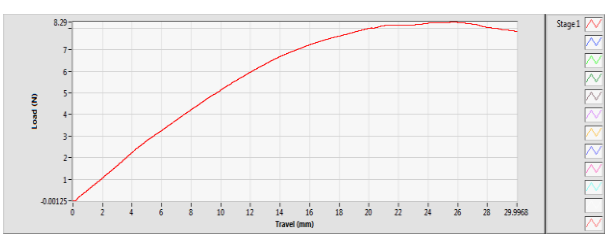
Fig4.5 Flexural Specimen-3 (230^0c, 20ccgm/hr)

Table 4.10 Results for Specimen-3 (230^0c,20ccgm/hr)

Specimen	Date &	Span	Width	Depth	Flextural stress1	Flextural stress2	Flexural strength
Total 1	Time	mm	mm	mm	MPa	MPa	MPa
4	10/04/19_15:05	64.000	13.160	5.863	-0.000	0.018	1.759

Specimen	Load@0.75mm	Load@1mm	Load@1.5mm	Load@2mm	Load@2.5mm	Load@1.25mm	Load@1.75mm
Total 1	N	N	N	N	N	N	N
4	0.357	0.492	0.770	1.054	1.345	0.639	0.912

Specimen	Load@2.25mm	Flextual strain- M	Chord Modulus	Load@1%	Secant Modulus
Total 1	N	mm/mm	MPa	N	MPa
4	1.206	0.220	9.000	0.589	12.499



Graph 4.5 Load vs Distance travel

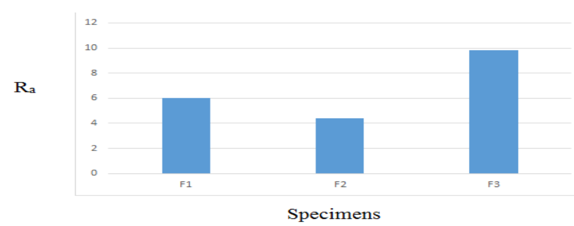
Table 4.11 Methodology for printing of 3D Parts

SL No	Orientation	Temp	Feed
1	Unidirectional	210^0c	15ccgm/hr
2	Unidirectional	220^0c	17.5ccgm/hr
3	Unidirectional	230^0c	20ccgm/hr

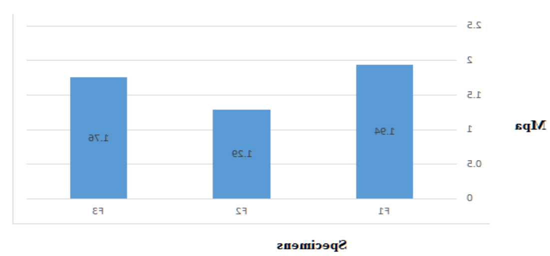
The flexural specimens are prepared by Thermoplastic Polyurethane (TPU) filament material. For this test, initially we given 1KN load to the machine. For this specimen we get flexural strength of 1.759 MPa. In this we plot the graph between load vs distance travel of specimen.

Table 4.12 Surface Roughness for Flexural Strength Specimens

S.No	Specimen	Surface Roughness (R_a)
1	F_1	6
2	F_2	4.4
3	F_3	9.85



Graph 4.5 Comparison of Surface roughness for TPU specimens



Graph 4.6 Comparison of Flexural Strength between TPU specimens

4.3 Izod Impact Strength:

Izod impact strength is defined as the kinetic energy needed to initiate the fracture and continue the fracture until the specimen is broken.

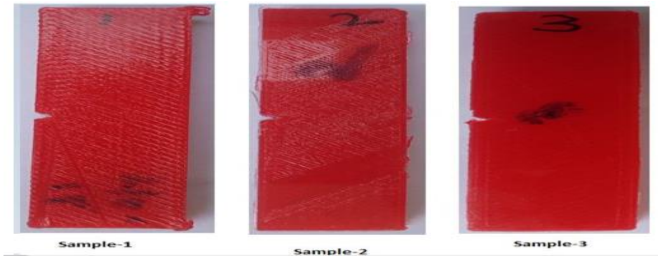


Fig4.6 Izod Impact Specimens

Fig4.7 Izod Impact Testing Machine

Table 4.13 Methodology for printing of 3D Parts

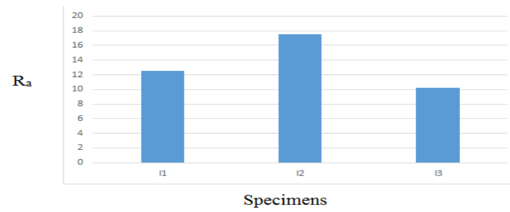
SL No	Orientation	Temp	Feed
1	Unidirectional	210^{0}c	15ccgm/hr
2	Unidirectional	220^{0}c	17.5ccgm/hr
3	Unidirectional	230^{0}c	20ccgm/hr

The Izod impact specimens are prepared by Thermoplastic Polyurethane(TPU) filament material. For this tensile specimens, I am varying some parameters like temperature and feed rate.In the Izod impact test, we didn’t get any results because of high elastic nature of the thermoplastic polyurethane material. For this test initially we applied 1KN,1.5KN load. But it is not broken.It simply bends and regains its original position.

Notched Thermoplastic Polyurethane Izod specimens were used to create notched ASTM D256 Izod specimens. Figure shows the notched bar. The sample was oriented with the notch perpendicular to the parting line; the top and bottom surfaces were minimally machined to maintain dimensions as well as perpendicularity. The 3D printinted thermoplastic polyurethane specimen. The Izod striker had a 0.66 mm radius and contacted the specimen at a 5° angle. A total of three specimens of each specimen were tested, but the specimen was not broken because of high elastic nature. In this Izod Impact testing,we didn’t get any results.

Table 4.14 Surface Roughness for Izod Specimens

S.No	Specimen	Surface Roughness (R_a)
1	I_1	12.49
2	I_2	17.5
3	I_3	10.25



Graph 4.7 Comparison of Surface roughness between TPU specimens

Table 4.15 Results of Izod impact test

Sample	Name of the Test	Units	Standard	Result
1	Izod Impact Strength, 23^0, Notched	J/m	ASTM D256 Method A:2010e1	NO RESULT
2	Izod Impact Strength, 23^0, Notched	J/m	ASTM D256 Method A:2010e1	NO RESULT
3	Izod Impact Strength, 23^0, Notched	J/m	ASTM D256 Method A:2010e1	NO RESULT

V. CONCLUSION

In this work, parts are prepared by Fused Deposition Modelling technique with the help of Thermoplastic Polyurethane filament (1.75mm dia). In this work, thermoplastic polyurethane filament used because it shows some superior properties like elasticity, high tensile strength, high elongation at break, good load bearing capacity, transparency of the material & high shear strength. But other materials like ABS, Nylon, PLA, PVA etc. These filaments are brittle in nature. They don’t show this type of superior properties like elasticity, high tensile strength etc.

Among tensile specimens, Specimen-3 (2300c & 20ccgm/hr) have high tensile strength among all the tensile specimens

Among flexural specimens, Specimen-1 (2100c & 15ccgm/hr) have high flexural strength among all the three specimens.

For Izod Impact test, we don't get any results, because of high elastic nature of the thermoplastic polyurethane material.

Scope of future work

Mathematical modelling and optimization studies can be done for the 3D printing parts produced using 3D printing process.

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