

EXPEIMENTAL STUDY ON FUSED DEPOSITION MODELING PROCESS PARAMETERS FOR IMPACT STRENGTH CARBON FIBER (PLA)

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ABSTRACT

Fusion Deposition Modelling (FDM) is a filament extrusion-based process that integrates CAD system, materials science, computer numerical control, and the extrusion process to fabricate 3D parts directly from a CAD model. The computer-controlled head move sin X–Y plane while help at form move sin the z-direction as required by the selected layer thickness. The main process parameter sin clade slice height (layer thickness), model tip diameter, model build temperature, part fill style, part interior style, raster width, raster angle, and raster air gap. In this work the effect of FDM process parameters, viz., layer thickness, print temperature, infill density and infill patter non-Impact strength and Printing time of PLA has studied. The printing process will be done by considering three levels for each parameter and full factorial design of experiments (3⁴) are conducted. The specimen design and process parameter setting has done in Ultima ker Cura software, those. STL files supplies to 3D printing Machine for printing of impact specimens. The impact test data will be analysed by conducting ANOVA. The result serval that layer thickness is having high importance in the additive manufacturing scenario. It is observed, Layer thickness is the major controlled process parameter while calculating the impact strength andprintingtimeof3Dprinted specimens

INTRODUCTION

Additive manufacturing (AM) or additive layer manufacturing (ALM) is the industrial production name for 3D printing, a computer-controlled process that creates three dimensional objects by depositing materials, usually in layers. Using computer aided design (CAD) or 3D object scanners, additive manufacturing allows for the creation of objects with precise geometric shapes. These are built layer by layer, as with a 3D printing process, which is in contrast to traditional manufacturing that often requires machining or other techniques to remove surplus material. Common to AM technologies is the use of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.

Binder Jetting: This technique uses a 3d printing style head moving on x, y and z axes to deposit alternating layers of powdered material and a liquid binder as an adhesive.

Material Extrusion: This common AM process uses spooled polymers which are either extruded or

drawn through a heated nozzle which is mounted on a movable arm. These builds melted material layer by layer as the nozzle moves horizontally and the bed moves vertically. The layers adhere through temperature control or chemical bonding agents.

Powder Bed Fusion: Powder bed fusion encompasses a variety of AM techniques including direct metal laser melting (DMLM), direct metal laser sintering (DMLS), electron beam melting (EBM), selective laser sintering (SLS) and selective heat sintering (SHS). Electron beams, lasers or thermal print heads are used to melt or partially melt fine layers of material after which excess powder is blasted away.

Sheet Lamination: Sheet lamination can be split into two technologies; laminated object manufacturing (LOM) and ultrasonic additive manufacturing (UAM). Laminated object manufacturing is suited to creating items with visual or aesthetic appeal and uses alternate layers of paper and adhesive. UAM uses ultrasonic welding to join thin metal sheets; a low energy, low temperature process, UAM can be used with various metals such as aluminium, stainless steel and titanium.

Vat Polymerisation: This process uses a vat of liquid resin photopolymer to create an object layer by layer. Mirrors are used to direct ultraviolet light

which cures the successive layers of resin through photo polymerisation. *Wire Arc Additive Manufacturing (Now known as Directed Energy Deposition Arc (DED-arc))*: Wire arc additive manufacturing uses arc welding power sources and manipulators to build 3D shapes through arc deposition. This process commonly uses wire as a material source and follows a predetermined path to create the desired shape. This method of additive manufacture is usually performed using robotic welding equipment.

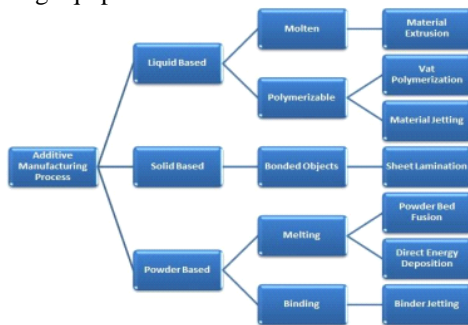


Figure 1.1: Additive Manufacturing Classification

1.1 3D PRINTING TECHNOLOGIES

1.1.1 STEREO LITHOGRAPHY (SLA): Stereo lithography 3D printers (known as SLAs or stereo lithography apparatus) position a perforated platform just below the surface of a vat of liquid photo curable polymer. A UV laser beam then traces the first slice of an object on the surface of this liquid, causing a very thin layer of photopolymer to harden. The perforated platform is then lowered very slightly and another slice is traced out and hardened by the laser. Another slice is then created, and then another,

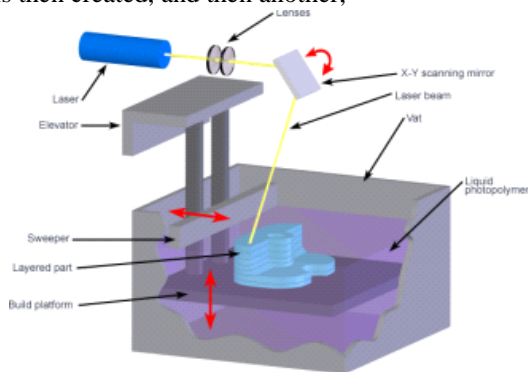


Figure 1.2: stereo lithography

1.1.2 LAMINATED OBJECT MANUFACTURING (LOM)

In the LOM technology, the layered material is rolled on the building platform. The material which

is coated with an adhesive layer and when the feeding roller starts heating to melt down the adhesive. After that the top layer will be glued to the previous one. A blade or a laser will be used to draw the geometry of the object to build and draw crosses on the rest of the surface to facilitate the extraction of the final objects.

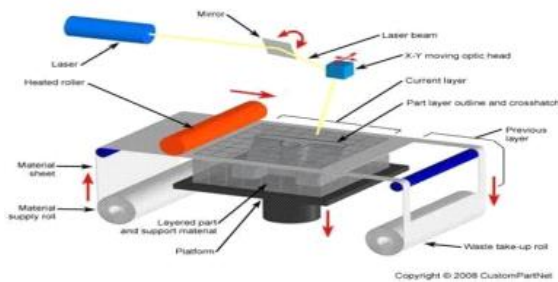


Figure 1.3: Laminated Object Manufacturing

Laminated Object Manufacturing works by layering sheets of material on top of one another, binding them together using glue. The printer then slices an outline of the object into that cross section to be removed from the surrounding excess material later. Repeating this process builds up the object one layer at a time. Objects printed using LOM are accurate, strong, and durable and generally show no distortion over time which makes them suitable for all stages of the design cycle. They can even be additionally modified by machining or drilling after printing. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper. Mcor's version of the technology makes LOM one of the few 3D printing processes that can produce prints in full colour.

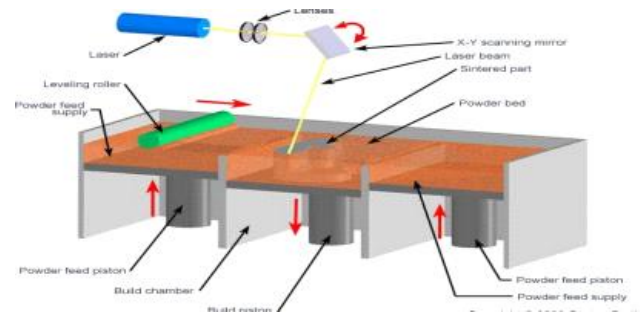


Figure 1.4: Selective Laser Sintering

Before printing, the powder is heated to a temperature just below the material's melting point. The recoating blade then deposits one layer height's powder on the build platform. SLS often uses 0.1mm / 100-micron layer heights. The CO2

laser then selectively sinters the powder according to the dimensions of the part solidifying it. It will trace the whole layer, before moving down to the next layer and starting again. This continues repeatedly, layer by layer, until the finished part is done

Polycarbonate (PC): Polycarbonate (PC) is a high strength material designed for engineering applications. The material has good temperature resistance, able to resist any physical deformation up to around 150°C. However, PC is prone to absorbing moisture from the air, which can affect performance and printing resistance. Therefore, PC has to be stored in airtight containers. PC is highly valued by the AM industry for its strength and transparency. It has a much lower density than glass, making it particularly interesting for designing optical parts, protective screens or decorative objects.

- PLA is easy to print since it has low warping.
- It can also be printed on a cold surface.
- It can print with sharper corners and features compared to ABS material.
- This material is available in different colours.

What are the characteristics of FDM 3D printing? While there are variations in the extrusion systems of fused deposition modelling 3D printers and parts may have different qualities, there are also some common characteristics (some good, some bad) that you can expect when you FDM print. **Warping:** Warping is one of the most common defects in FDM. When extruded material cools during solidification, its dimensions decrease. Since different sections of the print cool at different rates, their dimensions also change at different speeds. Differential cooling causes the build-up of internal stresses that pull the underlying layer upward, causing it to warp, as shown in figure. Warping can be prevented through closer temperature monitoring of the FDM system (namely, of build platform and chamber) and increasing adhesion between the part and the build platform.

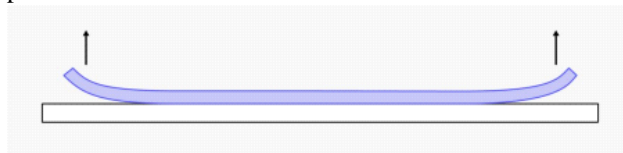


Figure 1.6 Wrapping

Design choices can also reduce the likelihood of warping:

- Large flat areas (such as those characteristic of a rectangular box) are more prone to warping and should be avoided when possible.
- Thin protruding features (such as those characteristic of fork prongs) are also prone to warping. Warping can be avoided by adding sacrificial material at the edge of the thin feature (e.g., a 200-micron thick rectangle) to increase the area that touches the build platform.
- Sharp corners warp more often than rounded shapes, so adding fillets to the design is good practice.
- Different materials are more susceptible to warping. ABS is generally more sensitive to warping than PLA or PETG.

Layer adhesion: Secure adhesion between the deposited layers is critical for an FDM part. When the molten thermoplastic is extruded through the nozzle, it is pressed against the previously printed layer. High temperature and pressure cause this layer to remelt and enable the new layer to bond with the previously printed part. Bond strength between the different layers is always lower than the base strength of the material. This means that FDM parts are inherently anisotropic: their strength in the z-axis is always smaller than their strength in the XY plane. For this reason, it is important to consider part orientation when designing parts for FDM.



Figure 1.7 Layer adhesive

For example, tensile test pieces printed horizontally in ABS at 50% infill were compared to test pieces printed vertically and found to have almost four times greater tensile strength in the XY print direction than the Z direction (17.0 megapascals compared to 4.4 megapascals) and elongated almost 10 times more before they broke (4.8% compared to 0.5%). Since the molten material is pressed against the previously printed layer, its shape is deformed to an oval. This means that FDM parts always have a wavy surface, no matter what layer height is used, and that small features, such as small holes or threads, may need to be post-processed after printing.

Support structure: Because molten thermoplastic cannot be deposited on thin air, some geometries require support structures. Support material might be difficult to remove, so it is often easier to design

parts to minimize the need for supports. Support is usually printed in the same material as the part. Support materials that dissolve in liquid also exist, but they are used mainly in high end desktop or industrial FDM 3D printers. Using dissolvable supports increases the overall cost of a print.



Figure 1.8 Supports

Infill and shell thickness: To reduce print time and save on material, FDM parts are usually not printed solid. Instead, the outer perimeter—called the shell—is traced using several passes, and the interior—called the infill—is filled with an internal low-density structure.

Infill and shell thickness greatly affect the part's strength. For desktop FDM printers, the default setting is 20% infill density and 1mm in shell thickness, which provides a nice compromise of strength and speed for quick prints. The main characteristics of FDM are summarized in this table:

Impact testing an impact test is used to observe the mechanics that a material will exhibit when it experiences a shock loading that causes the specimen to immediately deform, fracture or rupture completely. To perform this test the sample is placed into a holding fixture with the geometry and orientation determined by the type of test that is used and then a known weight generally but not always in the shape of a pendulum is released from a known height so that it collides with the specimen with a sudden force. This collision between the weight and specimen generally results in the destruction of the specimen but the transfer of energy between the two is used to determine the fracture mechanics of the material.

Purpose of impact testing: The purpose of an impact test is to determine the ability of the material to absorb energy during a collision. This energy may be used to determine the toughness, impact strength, fracture resistance, impact resistance or fracture resistance of the material depending on the test that was performed and the characteristic that is to be determined. These values are important for the selection of materials that will be used in applications that require the material to

undergo very rapid loading processes such as in vehicular collisions.

Types of impact tests: For a single impact test the three most popular types of tests are the Charpy V-notch test, the Izod test and the Tensile Impact test. These three tests all essentially determine the same characteristics of the material but differ in the orientation of the test sample which causes the sample to be stressed in different directions and involve a known weight released from a known height colliding with the specimen in its test fixture. All of these tests are useful in determining the impact mechanics of the test specimen.

Types of materials for impact testing: Nearly all materials may benefit from impact testing, but the most common types used are metals, plastics, woods, composites, ceramics, and polymers. Generally, these materials take the form of sheets of varying thicknesses or short rods depending on the test. However, most materials will experience either ductile or brittle failure depending of the type of test, the rate of loading and the temperature of the sample. Brittle failure of a material requires a small amount of energy to begin the crack or to cause the crack to grow until the sample fails. On the other hand, ductile failure of a material requires a much higher load to initiate and propagate the crack until failure.

2.0 LITERATURE REVIEW

Chamil Abeykoon (1) Title: Optimization of FDM parameters for improved PLA and ABS 3D printed structures This research is focused on studying the properties of 3D printed specimens with varying processing conditions such as infill pattern, infill density and infill speed, and also with different printing materials. A number of testing techniques such as tensile, bending, compression, differential scanning calorimetry (DSC), thermal gravimetric analysis (TGA), thermal imaging, and scanning electron microscopy (SEM) were used for performing a comprehensive analysis.

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Shivraj Yeole (3) TITLE: Tensile Testing and Evaluation of 3D Printed PLA Specimens as per

ASTM D638 Type-IV Standard This paper presents the evaluation of tensile strength of ASTM D638 Type IV specimens of PLA material additively manufactured using FDM based MakerBot desktop 3D printer and its simulation in ANSYS software.

G Ćwikła (4) TITLE: The influence of printing parameters on selected mechanical properties of FDM/FFF 3D-printed parts the printer was calibrated to produce the best quality prints. A number of tests, which led to the samples that do not have visible defects and imperfections, including layers de-lamination, discontinuities of specimen's shell and infill, were carried out.

Imre Fekete, Ferenc Ronkay (5) TITLE: the suitability of natural rubber (NR) toughened poly (lactic acid) (PLA)-based blends were investigated for additive manufacturing applications. Filaments for fused deposition modelling (FDM) were prepared with an NR concentration of 0 ... 20 wt.% using a twin-screw extruder. Subsequently, specimens were fabricated with a desktop 3D printer machine working on FDM principles.

3.0 DESIGN SOFTWARES USED

In this work, Taguchi robust design methodology is used to obtain the optimum conditions of the experimental data. Statistical software Minitab 15.0 is used to obtain results for Analysis of Mean (ANOM) and Analysis of Variance (ANOVA). The confirmation test is conducted for optimum conditions to validate the results. The knowledge of scientific phenomenon and past experience with similar product designs and manufacturing processes form the basis of the engineering design activity. However, a number of new decisions related to the particular design, the process architecture and parameters of the manufacturing processes a large amount of engineering effort is consumed in conducting experiments (either with hardware or by simulation) to generate the information needed to guide these decisions. Efficiency in generating such information is the key to meeting marketing windows, keeping development and manufacturing costs low and having high quality products robust design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost.

3.1. Taguchi's robust design:

The scientific approach to quality improvement is becoming more widespread in industrial practice. Designing high quality products and processes at low cost is an economical and technical challenge to the engineer. A systematic and efficient way to

meet this challenge is a method of design optimization for performance, quality and cost called robust design.

3.2. Robust design methodology:

Robust design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost. The main idea of robust design method is to choose the levels of design factors to make product or process performance intensive to uncontrollable variations such as manufacturing variations, deterioration and environmental variations. Dr. Genichi Taguchi has popularized the robust design method which employs experimental design techniques to help in identify the improved factor levels. Experimental design techniques are extremely effective for improving quality in problems that involve in a large number of factors. Taguchi's approach has been successfully applied by engineers in many leading Japanese and American companies for improving performance and competitiveness of their key products.

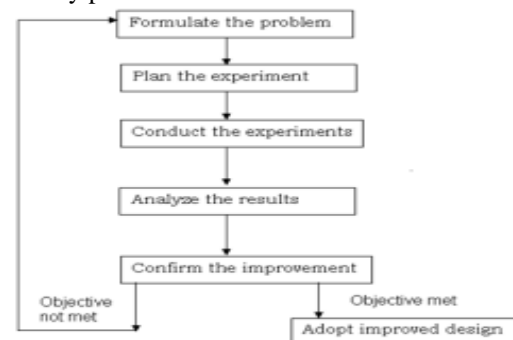


Figure.3.1: Experimental analysis

4. EXPERIMENTAL DESIGN AND SETUP

In this study, the Taguchi method was used to investigate the effects of important parameters like layer thickness, printing temperature, infill density, infill pattern.

Table No: 4.1 Process Parameters

FACTORS	LEVELS		
	1	2	3
Layer Thickness (A)	0.1	0.2	0.3
Printing Temperature (B)	200	210	220
Infill density (C)	75	85	95
Infill pattern (D)	Triangular	Cubic	Quarter cubic

The selected process parameters and its levels are mentioned in Table. In this work the parameters such as infill density and printing pattern are considered to analyse the effect of these parameters on the mechanical properties of 3D printed specimens.

4.1. Selection of orthogonal array: Selection of particular orthogonal array from the standard (O.A) depends on the number of factors, levels of each factor and the total degrees of freedom.

- i) Number of control factors = 4
- ii) Number of levels for each control factors = 3
- iii) Over all mean = 1
- iv) Total degrees of freedom of factors = $4 \times (3-1) = 8$
- v) Number of experiments to be conducted $(8+1) = 9$.

Based on these values and the required minimum number of experiments to be conducted are 9, the nearest O.A fulfilling this condition is $L_9(3^4)$. It can accommodate maximum of 4 number of control factors each at three levels with 9 numbers of experiments. Here the requirement is to accommodate four control factors at three levels, which can be easily done in this O.A. Table 4.2, shows the L9 standard orthogonal array.

Table No: 4.2 Taguchi L9 Orthogonal experimental setup.

No. of Experiments	Layer Thickness (A)	Printing Temperature (B)	Infill Density (C)	Infill Pattern (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	2	3
9	3	3	1	1

Table: 4.3 The L9 is designed for four parameters and three levels using design of experiment

S N O.	Layer Thickness (A)	Printing Temperature (B)	Infill Density (C)	Infill Pattern (D)

1	0.1	200	75	Triangular
2	0.1	210	85	Cubic
3	0.1	220	95	Quarter cubic
4	0.2	200	85	Quarter cubic
5	0.2	210	95	Triangular
6	0.2	220	75	Cubic
7	0.3	200	95	Cubic
8	0.3	210	75	Quarter cubic
9	0.3	220	85	Triangular

STEP 1: PART DESIGN IN AUTOCAD

Computer-aided design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. CAD software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD must convey information, such as materials, processes, dimensions, and tolerances, according to application specific conventions. CAD may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in three-dimensional (3D) space. CAD is an important industrial art extensively used in many



Figure 4.1: Impact specimen model

STEP 2: CONVERSION TO STL FILE FORMAT

An STL file is a triangular representation of a 3D surface geometry. The surface is tessellated logically into a set of oriented triangles (facets). Each facet is described by the unit outward normal and three points listed in counter clockwise order representing the vertices of the triangle. While the

aspect ratio and orientation of individual facets is governed by the surface curvature, the size of the facets is driven by the tolerance controlling the quality of the surface representation in terms of the distance of the facets from the surface. The choice of the tolerance is strongly dependent on the target application of the produced STL file. In industrial processing, where stereo-lithography machines perform a computer-controlled layer by layer laser curing of a photo-sensitive resin, the tolerance may be in order of 0.1 mm to make the produced 3D part precise with highly worked out details. However much larger values are typically used in pre-production STL prototypes, for example for visualization purposes.

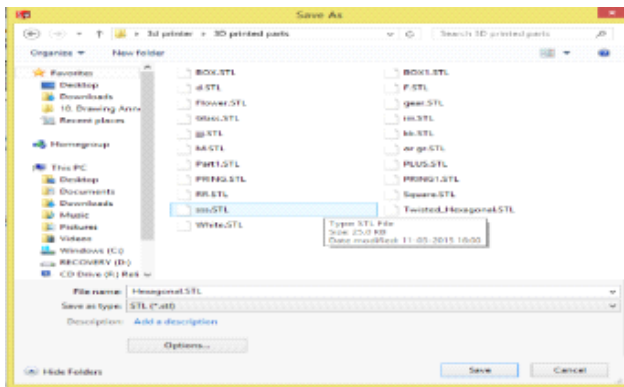


Figure 4.2 Conversion of .STL file format

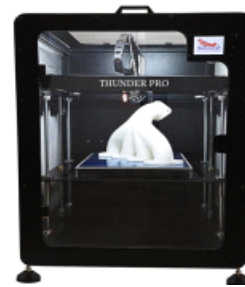
The native STL format has to fulfil the following specifications:

1. The normal and each vertex of every facet are specified by three coordinates each, so there is a total of 12 numbers stored for each facet.
2. Each facet is part of the boundary between the interior and the exterior of the object. The orientation of the facets (which way is "out" and which way is "in") is specified redundantly in two ways which must be consistent. First, the direction of the normal is outward. Second, the vertices are listed in counter clockwise order when looking at the object from the outside (right-hand rule).
3. Each triangle must share two vertices with each of its adjacent triangles. This is known as vertex-to-vertex rule. The object represented must be located in the all-positive octant (all vertex coordinates must be positive).

STEP 4: IMPORTING THE G-CODE FILE AND PRINTING IN ULTIMAKER CURA SOFTWARE

The file which is created then loaded in the Ultimate Cura which connects Arduino with the computer. From the Ultima Ker Cura software can give print command. The Arduino mega will thus send command to the stepped motor and get the 3D model.

4.2 3D printing machine



Garuda3d 'Thunder Pro' Enclosed 3D Printer is made of high-quality parts.

- Special Linear guide rails** give a smoother movement.
- Print Volume** of 300 x 300 x 300mm build volume;

- CoreXY Architecture** gives the best performance with speed.
- Auto Bed Levelling** eliminates the issue of frequent bed adjustments
- Dual Z-axis** gives the stable print

- Make in India** product
- Full Touch 3.5"** LCD

- Heated Bed** to print with High-Temperature Filaments

Sample specimens:



Figure 4.4: 3D printed Impact specimens

4.3 Impact Test on FDM Printed Impact Specimen

The Izod impact strength test is an ASTM standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen. The energy absorbed by the sample is calculated from the height the arm swings to after hitting the sample. A notched sample is generally used to determine impact energy and notch sensitivity.

The test is similar to the Charpy impact test but uses a different arrangement of the specimen under test. The Izod impact test differs from the Charpy

impact test in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration.

The test is named after the English engineer Edwin Gilbert Izod (1876– 1946), who described it in his 1903 address to the British Association, subsequently published in Engineering.

Specimen after impact test



Figure 4.6: Impact specimen after testing

5.0. DISCUSSION ON ANALYSIS RESULT

Compare the values of F-ratio tabulated with calculated F- ratio. If Calculated F- Ratio is greater than the tabulated this concludes that, the selected factors are significant for the process. The consolidated calculations of ANOVA are given in the Table 5.2.

Table 5.2: Basic Analysis of Variance of Impact strength

Factor	S.S	D. O. F	M.S. S	F-ratio (data)	F ratio (Table)	Result
Layer thickness	35.1432	2	17.5716	1405.7	4.26	Significant
Printing Temp.	0.1435	2	0.0717	5.736	4.26	Significant
Infill density	0.1475	2	0.0737	5.896	4.26	Significant
Infill	1.0807	2	1.0803	86.	4.26	Signif

pattern	07		17	536		ificant
Error	0.1128	9	0.0125			
St	36.6277	17				

Table 5.3: Analysis of Variance of Impact strength

Factor	S.S	D. F	M.S. S	F ratio (data)	F ratio (Table)	Percent age contribution
Layer thickness	35.1432	2	17.5716	1405.7	4.26	95.94
Printing Temp.	0.1435	2	0.0717	5.736	4.26	0.391
Infill density	0.1475	2	0.0737	5.896	4.26	0.402
Infill pattern	1.0807	2	0.5403	43.09	4.26	2.950
Error	0.1128	9	0.0125			0.307
St	36.6277	17				

Table 5.4: Summary of S/N ratios of Impact strength

Factors	Level 1	Level 2	Level 3
Layer Thickness (LT)	22.6465	21.7439	20.1438
Printing Temperature (PT)	21.6065	21.4367	21.5011
Infill Density (ID)	21.4352	21.5525	21.5566
Infill Pattern (IP)	21.5633	21.7002	21.2807

5.1.2. Selection of optimum parameters for Impact strength:

The optimum conditions are layer thickness at level 1 (0.1 mm), Printing temperature at level 1 (200°C), Infill density at level 3 (95 %) and Infill pattern at level 2 (cubic). Thus, the optimum condition obtained.

Table 5.5: Optimum set of control factors for Impact strength

Factor s/ Levels	Layer Thickn ess s (mm)	Printing Temperat ure e (°C)	Infill Densi ty (%)	Infill Patte rn
Optimu m	0.1	200	95	Cubic

CONCLUSION

Based on the results of the present experimental investigations, the following conclusions are drawn: High impact strength is observed in low layer thickness condition that is 0.1mm, average impact strength is observed in medium layer thickness that is 0.2 mm, very less impact strength is observed in high layer thickness. Layer thickness is having major contribution as compared to other process parameters. No other parameter is having considerable significance. The level of parameter with the highest S/N ratio is the optimal level. The individual factors effect on impact strength found to be significant, Layer thickness (LT) has major contribution of (95.94%) followed by Infill pattern (2.95%), infill density (0.402%), Printing temperature (0.391%). Printing time is more in low layer thickness condition, whereas it is very less in high layer thickness. Moderate printing time is observed in average layer thickness condition. In printing time of the component also, Layer thickness is having major contribution as compared to other process parameters. No other parameter is having considerable significance. Some parameters are significant and some other parameters are insignificant.

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