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COMPREHENSIVE ANALYSIS OF SELECTIVE LASER SINTERING (SLS) IN PROTOTYPING: MATERIAL SELECTION, TENSILE STRENGTH, HARDNESS AND DENSIMETER EVALUATION

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Abstract

Rapid prototyping has surfaced as a conducting technology in recent moments, permitting the immediate metamorphosis of computer-aided design files into operative prototypes. This invention significantly reduces the supereminent time needed to produce physical prototypes that are pivotal for design verification and functional analysis. The quality of RP prototypes relies heavily on parameters like door cure depth, subcaste consistency, exposure, ray power, temperature, and door distance. This study employs the Taguchi experimental design fashion to optimize these process parameters, aiming to understand their influence on part characteristics. Specifically, the exploration focuses on three crucial parameters: ray power, temperature, and part orientation. An orthogonal array of trials is designed using the Taguchi system, minimizing the number of experimental runs. Statistical analysis tools like analysis of variance (ANOVA) are applied to assess the impact of these parameters on the dimensional delicacy and micro-hardness of the SLS-produced corridor.

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1. Introduction

Prototypes were created utilizing the ray sintering method. Individual corridors can be created in limited numbers at an affordable price. The ray sintering approach builds a corridor with thermoplastic polymer grease paint. Radiant heaters heat the grease paint just below the polymer's point of melting once it spreads unevenly across the structure platform. The grease paint material used for the construction of this sample is PA2200. A face roughness tester is used to determine the face texture or face roughness of a material. This tester shows the measure roughness value (Ra) in micrometers or microns. This face finish (Ra) is calculated as the average roughness of the face measured in fine peaks and denes. The samples were tested on the UTM machine to check the tensile strength of the samples. This test system covers procedures used to estimate the tensile parcels of instances. The tensile test is principally a test that is exposed to control the stress until the instance breaks, the results of the test are generally used to prognosticate the material response under operation material selection, quality control, and other types of forces. The investigated samples were produced to comply with ASTM D638 standards in the case of strength tests. The machine in question has a maximum capacity of 500 mm/min. Three pieces of every kind of sample were generated to perform the necessary statistical computations.

This paper focuses on the effect of orientation and position on SLS parts considering 3 positions (H, V, and A) and 3 orientations (1, 2, and 3) at 0^o, 45^o, and 90^o. In all positions, parts are placed along the X and Y axes and placed at an angle of 45^o which is denoted by Z to investigate deviations in surface roughness, tensile strength, density, and porosity.

2. Literature Review

Detecting Surface Roughness on Selective Laser Sintering (SLS) parts with various measuring techniques is done by Launhardt et al.in which the Selective Laser Sintering additive manufacturing technique is used for producing three-dimensional parts. In the research work, tactile profile measurement is studied while keeping in view focus variation, fringe projection, and confocal laser scanning microscope [1].

The investigation provides an approach to identify the optimum process parameters to generate glass-filled polyamide plastic elements in SLS with better component integrity and reduced total expenses. For better surface polish and dimensional precision, the (GRA) look is used [2].

Powder bed fusion additive manufacturing procedures make use of Multi Jet Fusion (MJF) technology. Extremely low porosity of less than 1% was identified in the results of MJF-fabricated polyamide-11 segments, albeit the exact amount differed depending on the build orientation. By simultaneously preventing the negative consequences of insufficient intra-layer powder packing in the plane of the horizontal, which was observed in the horizontally oriented specimens, and the orientation of the inter-layer connect against the load direction, it was found that specimens focused at 450 relative to the build platform consistently performed best in terms of tensile mechanical properties [3].

Czesław Kundera and Tomasz Kozior researched the mechanical qualities of models developed with SLS technology. The investigation addresses specific mechanical properties of models produced with additive technology. Three angles 0°, 45°, and 90°—between the samples and the building platform were chosen. The uniaxial testing machine, smaller 3kN assessment, and the tribological tester T-15 type ring on a disc were used to carry out mechanical properties and tribological tests [4].

A comparison between parts constructed from polyamide 12 (PA12) printed by SLS and MJF was conducted. For studying porosities observed in printed samples, tomography is employed. Greater breaking strength is given by MJF technology than by SLS. The morphology and placement of orientation and printing methods varied [5]. The form and printing direction of the SLS part have an important effect on its actual mechanical performance. The lattice structure is being investigated by microscopic investigations [6].

Kinematic functionality is assessed and solid models are generated for seeing using RP. Superior surface quality and mechanical integrity are necessary for handling and testing the model. The study looks at how rough the surface (SR) of parts is made using the SLS approach. Several structures, involving bed temperature, scan, and laser, have been examined for different models [7].

Prototype quality may be verified utilizing the selective laser sintering (SLS) process, which takes orientation, bed temperature, and quality into consideration. For an optimization approach (ANOVA), the Taguchi method L9 (3 x 3) array is used [8]. Utilizing tensile testing as a characterization method, the energy density focuses on velocity, hatching distance, and laser power [9]. The tensile tests showed significant differences in strength features and energy absorption focused at 0 and 90 degrees for all materials, although only minor modifications in the elastic properties of two materials [10]. Employing sinter speed, lamp power, and print grey level, the study examined the surface topography of high-speed sintered parts. To examine the sample porosity, the areal texture of the surface was evaluated using X-ray computed tomography and focus variation microscopy. Scanning electron microscopy was used to elaborate on the surface topography [11]. Progress in part structure with SLS parameters, including energy density, is addressed in the research. An EOS P100 prototype machine was employed to come up with and produce an improved instance. Three different tasks were carried out using laser light that had various energy densities. The surface morphology and microstructure of sintered benchmark components have been investigated utilizing scanning electron microscopy [12]. As actual and measured values differ, the porous structure must be developed using fractal models [13].

3. Methodology

The process of additive manufacturing (AM), a layer-based automated fabrication technique, utilizes 3D-CAD data to create three-dimensional, scaled tangible items without the need for equipment that utilizes separate components. Additive production is the third pillar of the process of production as a whole. In 2009, the American Society of Mechanical Engineers (ASME) and the American Society for Testing and Materials (ASTM) started developing their uniform processes. The ASTM describes additive manufacturing as the process of combining materials to create goods based on 3D model data, typically layer upon layer, as compared to subtractive manufacturing methods.

3.1 Generic AM Process

The first stage is to create a 3D model of the item that will be released. This model can be created using reverse engineering techniques, such as using an object ray scanner for drawing, or computer-backed design (CAD) software. Additionally, the CAD train is transformed into an STL train, which is a common cumulative manufacturing train. Depending on the intricacy of the model and the power of the PC, this phase is thought to be the most straightforward conversion to an STL train that will tessellate shapes. Additionally, the train is divided into layers digitally. The STL train must be transferred, and the machine must be set up, for the third stage to minimize the material loss and optimize cost savings. Subcaste by subcaste, the computer-only machine builds the model in the fourth step. The overall quality is established by the subcaste consistency, which relies on the device and technique. The model can be taken out of the machine once the item is completely constructed and possibly cooled and cured. Drawing, polishing, painting, and finishing the face to the required excellence are instances of fresh post-processing.

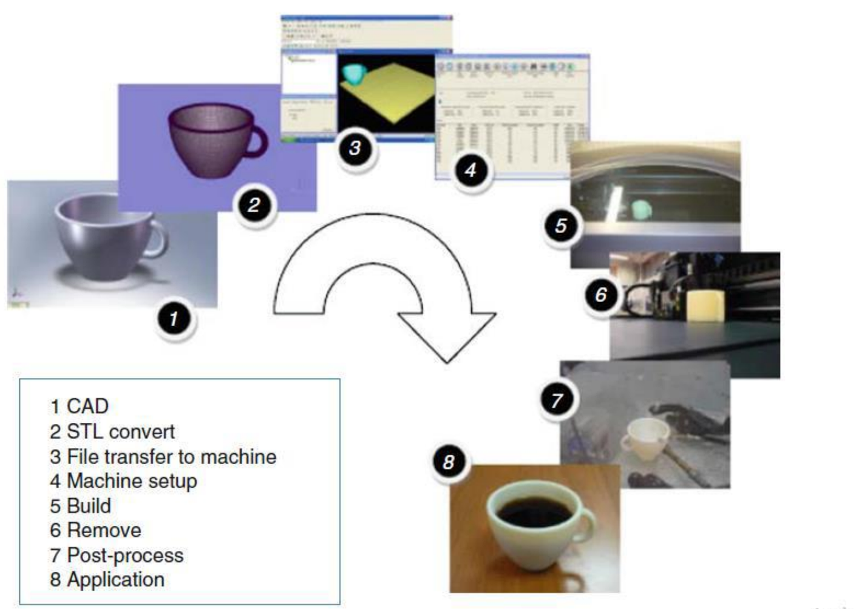

Figure 1. Generic AM Process

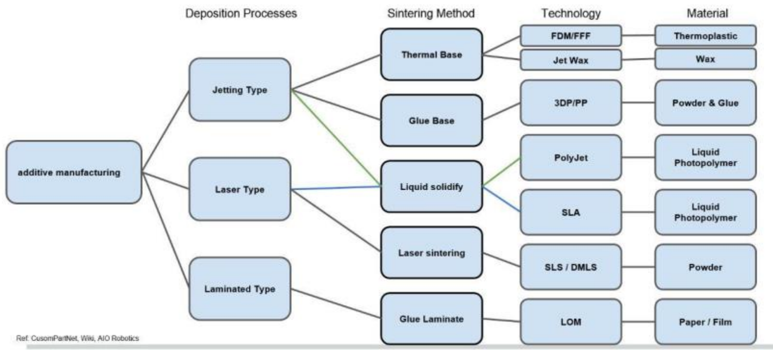

Figure 2. Types of 3D Printing

3.2 Technology

One of the earlier methods of AM to be commercialized was Powder Bed Fusion (PBF). The first powder bed sintering technique to be distributed was called Selective Laser Sintering (SLS), and it was developed at the University of Texas at Austin in the U.S. All the PBF processes shared an essential set of features. These include systems for introducing and polishing powder layers, techniques to control powder fusion to a particular spot of each layer, and one or more heat sources that encourage fusion between powder particles. [6] The SLS process was initially developed to use point-by-point laser scanning for manufacturing plastic prototypes. This approach equally works for metal powder and ceramic. A different source of warmth was used. Each layer of the powdery substance is presently undergoing melt deformation. As an array of materials (plastics, ceramics, metal composite materials, etc.) with characteristics that are comparable to several products have become accessible, the PBF process has expanded globally. These materials are also being employed more and more in the direct digital production of final products. Metals, ceramics, and polymers are engineering examples.

3.3 Equipment and Materials

The EOSINT P 385 uses the SLS process. This is a technology that uses 3D CAD data as input to provide 3D plastic, elastomer, metal, or ceramic parts. This machine can use polyamide material. The PA 2200 is especially used in ACDRI because it provides a very balanced characteristic profile. Made of pa2200 with excellent material properties such as excellent chemical resistance, excellent long-term behavior, high strength, biocompatibility according to ENISO 10993-1 and USP / LEVEL VI / 121o C, contact with food, etc. 3D printed parts EU Plastics Directive 2002/72 / EG.

Figure 3. SLS Machine (ACDRI)

3.4 Technical Data for Laser and Optics

Laser Type: CO_2 Laser
Nominal Power: 50W
Wavelength: 10.57 to 10.63 µm
Diameter of Focused beam: approx. 0.6mm
F-theta lens, focal length: 500mm
Exposure area (W X D): 350 X 350 mm
Beam Deflection speed: max. 5 m/s

3.4.1 Mechanical axes, Coordinates

Building Chamber (W x D x H): 350 x 350 x 620 mm
Recoater, X-Axis:
a) Travel: 690 mm
b) Travel speed adjust mode: max. 200mm/s
c) Travel speed automatic mode: max. 150 mm/s
Building platform, z-axis
a) Travel: 650 mm
b) Travel Speed: max. 6 mm/s
c) Resolution: 0.01 mm
Dispenser: Principle of Operation: slotted drum.

3.4.2 Heating: Process chamber heating

a) Principle of Operation: regulated infrared twin tube radiant heater, measurement of the powder bed temperature using radiation pyrometer (177o C)
b) Power Output: 3.0 kW

c) Removal chamber Heating
d) Principle of Operation: resistive heater coil with separate temperature 120^0C
e) Power Output: 1.6 kW

3.4.3 Hatching: Distance:0.3 mm, Speed: 4200 mm/s, Power: 78% and Beam Offset: 0.53 mm

3.5 Building process

The plastic powder material is applied layer by layer on the building platform and solidified layer by layer using a computer-controlled laser beam without additional binder. All sensitive components in the optics chamber are temperature-controlled. Nitrogen obtained from air is supplied to the process chamber. The inert gas atmosphere thus produced prevents the plastic powder from being damaged by atmospheric oxygen in the process chamber. The lens cleaning nozzle protects the F-Theta lens from dirt. The radiant heater adjusts the temperature of the build space to a defined value below the melting temperature of the plastic powder. Using a computer-controlled laser beam, the plastic powder material is applied layer by layer to the building platform and consolidated layer by layer without requiring a further binder. The visible chamber's delicate parts have been temperature-controlled. The process chamber obtains nitrogen from the air. As a result, the process chamber's inert gas atmosphere protects the polymer powder from the harmful impacts of ambient oxygen. The F-Theta lens is protected from dust by the lens cleaning nozzle. The construction area's temperature is controlled by the radiant heater to an appropriate temperature below the plastic powder's melting point.

3.6 Tensile Test

Tensile testing, also known as tensile testing, is a basic material science test that is exposed to controlled stress until the specimen breaks. The results of the tests are commonly used to predict material response under application material selection, quality control, and other types of forces. Extreme tensile strength, maximum elongation, and area reduction are the features that are directly measured in the tensile test.

Uniaxial tensile tests are most used to obtain the mechanical properties of isotropic materials. Plastic tensile test pieces (test pieces of dog bone shape with defined width and load stress psi) are manufactured to the dimensions of ASTM, EN, DIN, and ISO tensile test pieces. The tensile test piece is a standardized test piece cross-section. It has two shoulders and a gauge (section) between them. While the shoulders are large and easy to grip, the gauge part has a small cross-section, so deformation or breakage may occur at this part. The ASTM D638 standard for tensile testing of polymers was employed to carry out the tests. This standard indicates that samples up to 14 mm thick can be evaluated via this test method. Particularly helpful for qualitative characterization is this data. This standard was employed to calculate the appropriate characteristics for the part that was going to be tested: A 2-ton capacity UTM (manufacturer: Tinius Olsen) designed especially for polymers was employed for this test.

Figure 4. Tensile testing machine (Auto cluster, Pune) and sample loading on UTM

Tensile Tests on UTM were performed using the following parameters: Grip Separation: 20 mm, Thickness: 4 mm, Width: 4 mm, Test speed: 50 mm/min

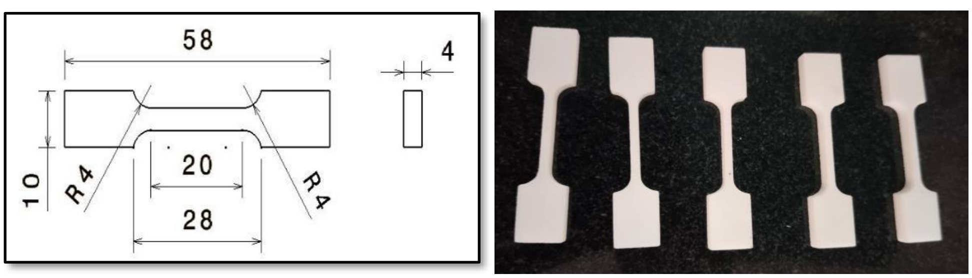

Figure 5. Dimensions of the tensile test sample

3.7 Hardness

The capability of a material to endure localized plastic distortion is referred to as its hardness. Hardness ranges from very hard substances like diamond and boron-carbide to different ceramics, soft materials, and even polymeric materials. Hardness is only one mechanical dimension; additional variables like vigor and durability must be taken seriously because hard items often break easily and have poor durability. Indentation, scrape, and rebound measurements of hardness represent a few of the methods used to measure hardness. Since nCATS has access to common Vickers hardness and micro-hardness devices, it also offers tools for examining hardness at the nanoscale employing indentation utilizing an infinitesimal force microscope and nanoindentation.

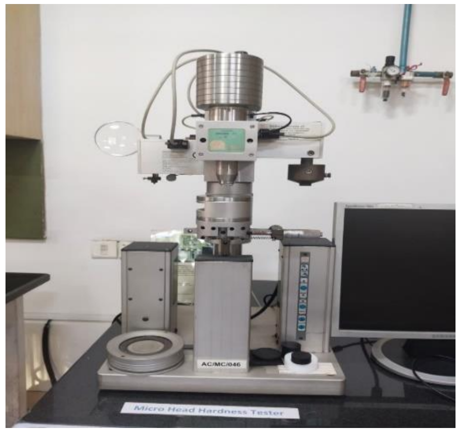

Figure 6. Hardness Tester

3.8 Densimeter

A densimeter is used for checking the density of specimens. This test method describes the determination of the specific gravity of solid polymer in the form of a molded item. The standard temperature for testing shall be between 150 to 350C and the relative humidity should be between 45% RH to 75% RH. The temperature range may be extended beyond these limits up to 10^0 C to 40^0 C for larger equipment. The accuracy of this meter is +/- 0.001gm. Make GIBITRE, ITALY, Model: ELECTRONIC BALANCE CHECKS 0.001G, UID: AC/MC/044, Sr No.: EBC 2007100, Range: 0.001 gm and Accuracy: +/- 0.001 gm

Figure 7. Densimeter

4. Conclusions

After performing tests on different models, the following table shows the results for Nylon material.

Sr No	Test Description	Test Method	Results
1	Tensile Strength	Customer Requirement	17.70 MPa
	Elongation		19%
2	Tensile Strength		14.41 MPa
	Elongation		17%
3	Tensile Strength		16.35 MPa
	Elongation		15%
4	Tensile Strength		15.88 MPa
	Elongation		13%
5	Tensile Strength		14.70 MPa
	Elongation		15%
6	Hardness Test	ISO 868	69 Shore D
7	Density Test.	ASTM D 792	0.995 g/cm³

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