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Developing Charcoal Reinforced Polymer Gear andEvaluating its Mechanical Properties using SLAProcess

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Abstract- Stereolithography (SLA), a technology that manufactures plastic components layer by layer, is based on ad- ditive manufacturing (AM). This idea forms the foundation of SLA. To enhance the application of parts cre- ated using stereolithography, a sizable amount of research has been conducted recently. CATIA software is used to create the CAD model of the gear, and CURA software is used to convert the CAD model into an STL file format. Magnetic stirring is then used to combine the charcoal and resin. Start stereolithography by shining a laser beam on the polymer composite material to initiate the process. The amount of charcoal powder has fluctuated between 0 and 1 weight percent. Three different material compositions were used to synthesize the SLA components needed to analyses friction and wear. Combiningfactors, A = 1, B = 0.2, and C = 80 yielded the maximum SNRA mean value of 53.15155. Priority should be given to this combination because it typically results in the least wear loss.

I. INTRODUCTION

Rapid prototyping and production have been completely trans- formed by the invention of stereo lithography, sometimes known as SLA. It is one of the cutting-edge 3D printing tech- niques and has enormous potential in a variety of markets, in- cluding the automotive, aerospace, medical, and consumer products sectors.

Fundamentally, stereolithography builds complex three-dimen- sional objects out of a liquid resin in a layer- by-layer fashion. A computer-aided design (CAD) model is the first step in the process; it is divided into multiple thin layers. The liquid resin is then selectively cured and solidified by being sequentially subjected to an intense UV laser beam. Stereolithography stands out for its exceptional precision and capacity to produce intricate, highly detailed geome- tries with smooth surface finishes. The flawless bonding of the cured layers produces durable prototypes or end-use products.

Engineers, designers, and manufacturers may quickly iterate and improve their designs thanks to SLA technology, which also lowers the costs and time-to-mar- ket of conventional production processes.

II. LITERATURE REVIEW

Various research papers have been discussed about the Developing Charcoal Reinforced Polymer Gear and Eval- uating its Mechanical Properties using SLA Process. Based on factors such as simplicity of design and ease of procurement, the SLA has been preferred. On studying few research papers and case studies on SLA printed 3d materials.

Zhang, Y., Shi, Y., and Yang, J. (2018) investigate how different process factors affect surface roughness in SLA, and then suggest an optimization plan to improve the surface quality of printed items. The Surface and Laser Applications journal published the results of this study. It underlines how crucial it is to optimize variables like layer thickness, exposure time, and scanning speed in order to achieve superior surface finishes.

The reviewed article by Wang, X. and Shaw, L. L. (2017) gives a summary of the methods used in additive manufacturing, including SLA, for process monitoring and control. It underlines the importance of real-time monitoring and feedback control systems throughout the printing process in order to maximize the efficiency of the process parameters and maintain a steady level of part quality.

Mani, M., and Zhang, W. (2017) raised awareness to the SLA-specific optimization techniques in the context of bio fabrication applications. It focuses on choosing biomaterials with the right properties, optimizing process variables for cell survival and tissue creation, and post-processing techniques for enhancing biocompatibility

Gong, H., Guo, Y., and Gao, W. (2019) Analyze the potential for improving component quality and lowering material consumption through the optimization of support structures in SLA. It explores the potential for creating algorithms and software tools to create the best support designs by considering factors including support density, geometry, and position.

An optimization strategy that makes use of grey relational analysis has been presented by Zeng, X., Lee, H. P., and Tor, S. B. (2017) to make SLA's surface roughness better. In this work, the relationship between several process variables, including layer thickness, scanning speed, and exposure time, and their effects on surface roughness are investigated. Grey relational analysis has the potential to be a useful tool for the optimization of SLA methods, as the research reveals

In Bai, S., Li, Y., and Shi, Y. (2020), by combining Taguchi design of experiments and Grey relational analysis, a hybrid optimization technique is suggested for identifying the best process parameters for SLA. It shows that the suggested strategy is helpful in boosting the overall performance of the process and considers both the dimensional accuracy and the sur- face quality as optimization objectives.

The research conducted by Ahn, S. H., Montero, M., and Odell, D. (2002) explores the optimization of SLA process variables to boost printing accuracy and output rate. The quality of the component and the time required to make the part are both examined in relation to variables such as laser power, scanning speed, and layer thickness. The study clarifies how the process's components relate to one another and how those factors affect SLA performance.

Zhou, C., et al. (2018) provides a thorough analysis of several 3D printing techniques for polymer matrix composites, including stereolithography (SLA). The potential of selective laser sintering (SLA) to create intricate geometries with precise reinforcement distribution is the main topic of this paper. It examines the difficulties involved in fabricating composite structures, including material selection, process requirements, and difficulties.

III. OBJECTIVES

- To develop charcoal powder reinforced polymer based composite parts by stereo lithography technique.
- To investigate the effect of charcoal powder content on wear strength of SLA parts
- To optimize the process parameter to achieve best possible mechanical properties (wear strength) in SLA parts using Taguchi Orthogonal array.
- To characterize charcoal powder reinforced SLA parts for dispersion, and surface finish and to compare with unreinforced parts.

IV. METHEDOLOGY

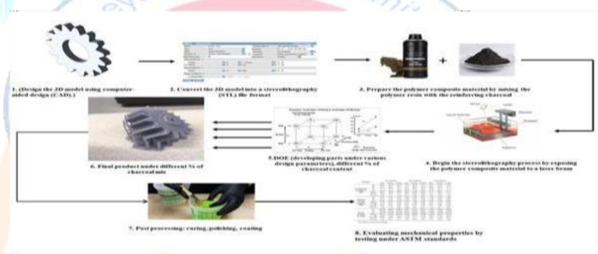

Fig:1 methodology flow chart

- Design 3D model using computer aided de-sign (CAD)
- Convert 3D model into STL (stereolithogra-phy) format
- Prepare the polymer composite material by mixing the polymer resin with the reinforcing charcoal
- Begin the stereolithography process by expos-ing the polymer composite material to a laser beam
- DOE (developing parts under various design parameters),different percentage of charcoal content
- Final product under different percentage of charcoal mix
- Post processing, curing, polishing, coating
- Evaluating mechanical properties by testing under ASTM standards

V. SCOPE OF WORK

The technologies of manufacturing have seen significant advancements in recent years, making these years an exciting time for the field. The term "additive manufacturing" refers to a number of technologies that enable the fabrication of physical objects directly from CAD data sources. Additive manufacturing is a generic term for these technologies. These processes are based on the additive principle for the fabrication of parts, in contrast to traditional methods of manufacturing such as milling and forging, which are respectively based on the subtractive and formative principles for part fabrication. The most significant benefit of using RP processes is that an entire three- dimensional (three-dimensional) consolidated assembly can be fabricated in a single setup without the use of any tools or direct involvement from a person.

Additionally, the degree of difficulty the component geometry presents does not have an impact on the process of part manufacture. Due to its many advantages, additive manufacturing has attracted a lot of interest from the manufacturing sector. In order to gain an advantage over their competitors, these industries are seeking for ways to incorporate frequent and quick changes in production while still meeting client demands. One of the commercially available processes is Stereolithography, sometimes referred to as SLA.

VI. EXPERIMENTAL DETAIL

Photopolymer Resin The type of resin that is most typically used in the stereo lithography (SLA) process is photopolymer resin. Photopolymer resins are resins that have been developed to start polymerizing when exposed to a specific wavelength of light, most frequently ultraviolet (UV) radiation.

These resins have a photo initiator and a liquid monomer as their main building blocks. The liquid monomer functions as the fundamental element of the chain as the liquid photo initiator initiates the polymerization reaction when exposed to ultraviolet light. The UV light that the SLA printer emits causes the photo initiator in the resin to absorb light energy. This starts the curing process, which causes the resin to solidify and layer by layer create a solid object.

SLA may employ photopolymer resins, which can be found in a variety of formulae, each with a unique set of characteristics and benefits. These formulas are flexible and can be changed to provide a wide range of material properties, including as tensile strength, pliability, transparency, and resistance to high temperatures. Examples of typical photopolymer kinds include standard resins, engineering resins, castable resins for investment casting, and dental resins for dental purposes

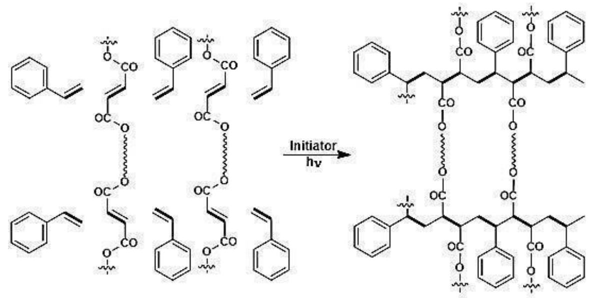

Fig:2 Chemical structure of Photopolymer resin

Hardness	73-82 (Rockwell)
Tensile Strength	41-46Mpa
Elongation	05-11%
Flexural Strength	40-55Mpa
Density	1.04 g/cc

Table:1 Mechanical and Physical Properties of PLA Plastic

Filler Material: Charcoal Powder

To enhance the properties of the composite material that is created as a result, charcoal powder was employed as a filler material in the photopolymer resin. Charcoal powder can be used in a variety of ways as filler. By adding charcoal powder to polymers, it is possible to boost the material's mechanical properties while also making it more robust. The high carbon content and porous structure of charcoal may all contribute to a 30 improvement in the stiffness, strength, and impact resistance of the polymer composite. When using charcoal powder as a filler in polymers, it is important to take into account factors such the loading amount and dispersion within the polymer matrix. To ensure that the filler is evenly distributed throughout the polymer

Fig:3 charcoal powder

The experiment used stereo lithography (SLA), and the effects of three variables—hatch spacing, post-curing period, and charcoal filler content—were examined using the Taguchi L9 orthogonal array design. All other parameter values were maintained at the corresponding levels. Here is a thorough explanation of the experiment's methodology: In order to adequately study the impacts of the three variables at three levels each, the Taguchi L9 orthogonal array design was adopted. Hatch spacing was set at 0.1 millimeters, 0.15 millimeters, and 0.2 millimeters; post-curing time was set at 40 minutes, 80 minutes, and 120 minutes; and charcoal filler content was set at 0%, 0.5%, and 1.0%, respectively. The chosen photopolymer resin was added to the resin vat to prepare it for the experiment. In order to ensure that the filler material was clean, devoid of impurities, and had the right particle size, charcoal powder was purchased. To reach the desired filler content levels stated in the orthogonal array, the necessary amounts of photopolymer resin and charcoal powder were measured, combined, and added to the mixture. The vat of the SLA printer was filled with the resin mixture and charcoal filler. Other parameters like layer thickness, exposure time, and resolution were set to fixed

values using the software that came with the SLA printer. The printer was programmed to create nine samples with various hatch spacing, post-curing period, and charcoal filler configurations based on the orthogonal array design. Dimensional accuracy, surface quality, mechanical characteristics, and other crucial criteria were measured. To ascertain the effect of each element on the final properties of the SLA-printed goods, the findings from various combinations of hatch spacing, post-curing time, and charcoal filler content were studied. With all variables held constant, this experimental strategy allowed for a methodical evaluation of the effects of hatch spacing, 37 post-curing time, and charcoal filler content on the SLA-printed samples. The information gathered was utilized to determine the best settings for these factors and to learn more about their effects on the effectiveness and quality of the SLA-printed objects.

Factor	Levels		
	1	2	3
Charcoal Content(A)Wt%	0	0.5	1
Hatch spacing (B), mm	0.1	0.15	0.2
Post curing time (C), minutes	40	80	120

Table:2 Factors and Their Levels

EXPDT No.	Charcoal Content(A) Wt%	Hatch spacing (B) mm	Post curing time (C), minutes
1	0	0.1	40
2	0	0.15	80
3	0	0.20	120
4	0.5	0.1	40
5	0.5	0.15	80
6	0.5	0.20	120
7	1	0.1	40
8	1	0.15	80
9	1	0.20	120

Table:3 Taguchi's L9 Orthogonal Array

MINITAB Software: A reliable piece of software that is widely used for data analysis and statistical modelling is the MINITAB statistical software application. It is suitable for carrying out both basic and complex statistical computations because it features an intuitive user interface and a wide range of statistical tools.

Additionally, MINITAB is Microsoft Excel compatible, making it simple to move data between the two programmers and analyses it there as well.

One can utilize MINITAB to perform statistical analysis on the data that was acquired in the context of the prior discussion on the experiments that used the Taguchi L9 orthogonal array design. It is clear that the MINITAB 16 software is being used to assess the results of the experiment using the Taguchi method because the Taguchi method is selected on the worksheet for the programme, as shown in the image. The worksheet included with MINITAB offers an organized environment where the experiment's data can be entered and organized. Columns can be used to structure the data, with each column representing a separate variable or a level of an existing variable. In You can insert the specific levels of hatch spacing, post-curing time, and charcoal filler content that are specified in the orthogonal array in the worksheet.

After the data have been entered, a wide range of statistical tools are available in MINITAB that may be used to analyses the data and do the necessary computations. You can use MINITAB to do an analysis of variance (ANOVA) in the context of the Taguchi L9 design to assess the significance of the variables and their interactions. Each variable's and an interaction's sum of squares, degrees of freedom, mean squares, F-values, and p-values can be calculated using MINITAB's ANOVA tool.

Additionally, it can offer graphical representations of the data, such as plots and charts, to help with understanding the outcomes. An efficient analysis of the experimental data is feasible thanks to the Taguchi design that MINITAB offers. The properties of the SLA-printed samples can then be determined by determining the important factors and the amounts at which they are involved. The outcomes of this statistical analysis aid in establishing the appropriate hatch spacing, posturing time, and amount of charcoal filler settings, which eventually improve the quality and functionality of the SLA-printed objects.

VII. RESULTS AND DISCUSSION

Macrostructure analysis of SLA parts:

An important method for assessing the attributes and quality of SLA (Stereolithography) parts produced under various printing circumstances is macrostructure analysis.

The macrostructure and microstructure of the part are also subjected to these examinations' microstructure. By shedding light on both the external and interior characteristics of the printed parts, these analyses aid in the evaluation of their mechanical characteristics, dimensional correctness, and surface quality.

The macrostructure's analysis focuses on both the printed pieces' outward properties and the overall structure. It necessitates both visual inspection and measurements of numerous macroscopic factors, such as the following: To ascertain whether the printed part's dimensions correspond to those of the original, measurements are obtained and comparisons are performed.The smoothness, finish, and existence of any obvious flaws like layer lines, roughness, or surface imperfections are all inspected. It is verified that the printed part has the proper overall geometry, structural integrity, and form. This guarantees that it complies with the design's requirements. To find any signs of delamination or inadequate adhesion, interlayer adhesion is tested. The quality, integrity, and performance of the SLA parts may be thoroughly understood by integrating the investigation of the macrostructure and the microstructure. These studies assist in identifying potential issues, maximizing the printing settings, and making sure that the printed parts adhere to the desired specifications and functional requirements.

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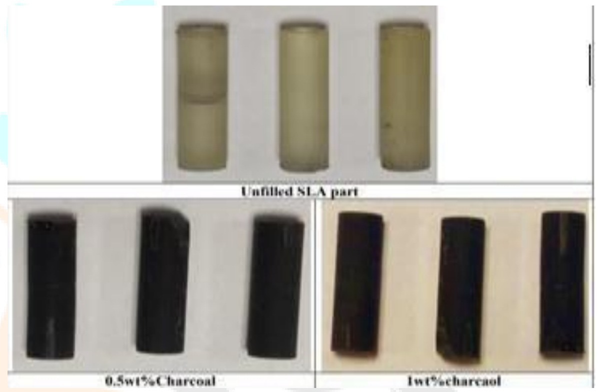

Fig: 4 test specimens

Signal-to-Noise Ratio Analysis:

By examining the mean values of the response variable, SNRA (Signal-to-Noise Ratio Analysis), a technique employed in Taguchi analysis, is used to assess how well a process or system is working. SNRA assists in determining the ideal set of variables or levels that maximize the intended result while minimizing response variability. In order to explain the SNRA mean values in Taguchi Analysis, it is necessary to comprehend the signal-to-noise ratio notion. The target value or ideal response that we aim to attain is referred to in this context as the signal, and the variation or deviation from the objective is referred to as the noise. Three SNRA kinds are frequently employed in Taguchi Analysis: the smallethe-better, the larger-the-better, and the nominal-the-best.

The SNRA is derived using the following formula: SNRA = -10 * log(mean2/variance) for responses where smaller values are preferred (e.g., flaws, mistakes). A greater SNRA number in this instance denotes better performance because it suggests that the mean value is nearer the target and the variation is kept to a minimum in the current experiment, lesser wear loss values are preferred.

We have the factors reinforcement (A), hatch spacing (B), and post-curing time (C), along with the wear loss values and SNRA mean values that correspond to those factors, in the table for the Taguchi Analysis that was provided. To determine if a process or system is effective, Taguchi analysis uses a statistical technique known as the signal-to-noise ratio analysis, or SNRA. By accounting for variability or noise, it offers a measurement of how close the mean 42 response is to the desired target.

The wear loss data is the main input used to compute and present the SNRA mean values in the table below. Since the primary goal in this situation is to minimize wear loss, a higher SNRA mean value denotes better performance in terms of a reduced overall wear loss. When we take a look at the table with the SNRA mean values, we can see that higher values indicate better performance:

The combination of factor A = 1, factor B = 0.2, and factor C = 80 produced the highest possible SNRA mean value of 53.15155. This value was obtained by multiplying factor A by factor B. This demonstrates that this combination results in the least amount of wear loss on average; consequently, it is the combination that should be prioritized.

A	B	C	**Wear Loss**	SNRA	MEAN
0	0.1	40	**0.0033**	49.62972	0.0033
0	0.15	80	**0.003**	50.45757	0.003
0	0.2	120	**0.0032**	49.897	0.0032
0.5	0.1	80	**0.0031**	50.17277	0.0031
0.5	0.15	120	**0.0029**	50.75204	0.0029
0.5	0.2	40	**0.0026**	51.70053	0.0026
1	0.1	120	**0.0028**	51.05684	0.0028
1	0.15	40	**0.0024**	52.39578	0.0024
1	0.2	80	**0.0022**	53.15155	0.0022

Table:4 wear test results

VIII. OUTCOME

1. Improved mechanical strength: Charcoal, when properly incorporated into a polymer matrix, can enhance the mechanical properties of the gear. The expected outcome would be an increase in the gear's strength, toughness, and resistance to wear and deformation compared to a traditional polymer gear.

2. Enhanced heat resistance: Charcoal, being a carbon-based material, has good thermal stability. The incorporation of charcoal into the polymer gear can improve its heat resistance, allowing it to withstand higher temperatures without significant degradation.

3. Reduced weight: Charcoal is relatively lightweight compared to other fillers or reinforcements. By using charcoal as a reinforcing material, the overall weight of the gear can be reduced, which is beneficial for applications where weight savings are critical, such as in aerospace or automotive industries.

4. Improved dimensional stability: Charcoal-reinforced polymer gear can exhibit better dimensional stability, meaning it will maintain its shape and size more effectively under various operating conditions. This outcome is particularly advantageous when precision and accurate gear performance are required.

Fig: 5 final developed product

IX. CONCLUSION

- The absence of observable flaws in composites with and without char- coal filler demonstrates that the SLA printing method has been successfulin creating parts free of obvious faults such layer lines, roughness, or sur-face imperfections under the examined conditions.
- The SLA parts' observed good macrostructure shows that the printing parameters and settings utilized in the current experiment were appropriate and successful in producing the desired overall shape, geometry, and struc- tural integrity of the printed parts.
- Successful printing of SLA components under the researched conditionsis indicated by the lack of obvious faults in the macrostructure analysis, which emphasizes the significance of detailed analysis to evaluate quality,optimize parameters, and fulfill preferred requirements.
- The maximum SNRA mean value of 53.15155 was obtained when factor A = 1, factor B = 0.2, and factor C = 80 were combined. Since this combi- nation generally causes the least wear loss, it should be given priority.
- The lowest SNRA mean value, 49.62972, was produced by the combi- nation of factors A = 0, B = 0.1, and C = 40, showing a substantially higher wear loss compared to other combinations.

- By examining the mean SNRA values, we can identify the variables andtheir relative importance in reducing wear loss. This information aids in determining the ideal combination of elements for minimizing wear and improving use of materials.
- The impact of Factor A (reinforcement) on wear loss is statistically sig- nificant. Compared to Factors B and C, it has a greater impact. To ascertain whether amount or levels of Factor A cause less wear loss, it is essential to examine the various levels.
- Although its impact is not as great as Factor A's, Factor B (Hatch spac- ing) also shows a statistically significant impact on wear loss. To deter- mine the level or levels of Factor B thatlead to less wear loss, it is crucial to analyses the levels of this factor.
- When compared to Factors A and B, Factor C (Post curing Time) has a significantly smaller impact on wear loss. Even while it might not be as statistically significant, it still has someimpact on wear loss. Studyingthe concentrations of Factor C required comprehending how they con- tribute to wear and tear.
- The F-values offer details on the size and importance of each factor'seffects on wear loss. Factor A has the most bearing on this analysis, fol-lowed by Factor B and then Factor C. In the desired application, adjust-ing the levels of each element can assist prevent wear and tear.
- According to the data, Factor C levels have a relatively smaller impact on wear loss than Factor A levels do. Factor A levels appear to have the most impact. It is feasible to make wise decisions by comprehending these relationships. reducing wear and boosting durability during print- ing.

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