EXPERIMENTAL INVESTIGATION ON MECHANICAL BEHAVIOUR AND OPTIMIZE PARAMETERS OF FDM PRINTED CARBON FIBER REINFORCED PET-G FOR MAV APPLICATION'S

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Abstract :

Fused deposition modeling (FDM) is an additive manufacturing technique used to fabricate intricate parts in 3D, within the shortest possible time without using tools, dies, fixtures, or human intervention. With the development and application of additive manufacturing technology, the mechanical properties of parts have become more important. The performance of FDM built parts exhibit high dependence on process parameters, and it can be improved by selecting suitable parameters. The present study focuses on the effect of process parameters in the fused deposition modeling of PLA material. The input parameters taken as fill density, print speed, filling shape and layer thickness. A design of experiments are conducted based on Taguchi L9 orthogonal array. The output responses are taken as tensile strength and compression strength of test specimen.

Key words: Fused deposition modeling, Optimization, Tensile strength is a new optimizing technique for performing the prediction, grey relational analysis and decision making in many areas. In this paper, the use of grey relational analysis for to optimizing the machining process parameters for the work piece is surface roughness and the metal removal rate is introduced. In order to improve the quality and productivity the present study highlights the optimization of CNC milling process parameters like speed, feed rate, depth of cut and different coated HSS tools to provide a good surface finish as well as high material removal rate. Hence a multi objective optimization problem has been obtained which can be solved by the hybrid Taguchi method comprising of grey relational analysis. Finally, Taguchi method has been used to solve the optimization problem.

I. INTRODUCTION:

In recent years, the biodegradable composites draw many attentions in aerospace applications (MAV), as the increasingly serious environmental pollution problems caused by thermosetting composites. Mohanty et al. (2000) reviewed the application of biopolymers and considered that the biopolymers offer environmental benefits including biodegradability, renewability and less greenhouse gas emissions. Polyethylene terephthalate (PET-G) is a kind of biodegradable material derived from renewable resource and possesses good mechanical properties, which makes it promising an ecologically friendly material for composite applications. At least one species of bacterium in the genus Nocardia can degrade PET with an esterase enzyme. Japanese scientists have isolated a bacterium Ideonella sakaiensis that possesses two enzymes which can break down the PET into smaller pieces that the bacterium can digest. A colony of I. sakaiensis can disintegrate a plastic film in about six weeks.

II. LITERATURESURVEY:

Z Zhou et al: Plating on plastics" is a term used to depict the embellishing or useful application of metal onto plastic substrates utilizing the procedure of electroplating. Before plastics can be electroplated, they initially need to be metalized. This is attained by etching the surface of the substrate under consideration and covering the roughened surface with traces of a valuable metal. This valuable metal gives the "seeds" for deposited of a thin layer of nickel or copper by electroless deposition. In their work on electroplating of stereolithography (SL) polymers have reported that, "Metal-coated SL polymer has the properties of a bonded composite material. The hard and stiff metal coating firmly anchored in the SL material, confers new mechanical properties on the material that differ from those of the individual components".

Chandrasekhar. U, Venkatesh. K, Elangovan. K, Rangaswamy. T,et al.

2011 Integrated use of rapid prototyping and metal plating techniques for development of Micro Air Vehicles. This paper describes the collegial application of rapid prototyping and metal plating technologies for the development of MAV. FDM and stereolithography are used to fabricate thermoplastic MAV structure materials, since thermoplastic have low strength, and to make them airworthy, these substrates are coated with layers of metal through electroless and electrolytic deposition process. Experiments are conducted on metal plated thermoplastic test specimens and their mechanical behavior and structural integrity properties are evaluated, there by realizing flight worthy MAV structure. This journal recommends the use of 100µm layer specimens because the compressive stress is uniform and less in magnitude. This journal also recommends the use of quasi hollow structured aero foils. Apparatus for production of three-dimensional objects by Stereolithography (Hull, 1986) Stereolithography is a system of generating three dimensional objects at the selected surface of the fluid medium, which is capable of altering its physical state in response to appropriate synergetic stimulation, thereby resulting in buildup of three-dimensional CAD model layer by layer. It is a method and approach for making solid objects by successively printing thin layers of curable material e.g.: UV curable material one on top of the other. This method harnesses the principles of computer-generated graphics in combination with stereolithography to produce three dimensional objects to simultaneously execute CAD and CAM in producing three dimensional objects directly from computer instructions. This apparatus makes use of a movable spot, which houses a UV light. This UV light traces one cross section at one instant of time, once this is done the movable table on which the model is being fabricated moves down thereby forcing a fresh layer of fluid over the surface. Making use of this method of producing parts reduce the idle time between design and production of three-dimensional parts.

Mithun V Kulkarni, K Elangovan, K Hemachandra Reddy, S A Rodriguez Arthur

Present research, ABS (acrylonitrile- butadiene styrene), plastic is electroplated with copper (Cu) and Nickel (Ni) electrolytic solutions. The coating thickness of Cu and Ni layer approximates to 5µm and 35µm respectively. These coated samples are subjected to FEM analysis to make a note of increase or decrease in the mechanical strength (Tensile and Compression). The obtained results are compared with the uncoated samples. The result of the simulation indicates that coating bestows an increase in strength to the ABS samples.

The work here demonstrates the mitigation of a problem associated with 3D printing as a whole through novel materials development and analyzes the effects of adding a wide variety of materials on the physical properties of a thermoplastic base resin.

III. METHODOLOGY:

Designing for 3D Printing

The first step in generating an FDM part is to create a three-dimensional solid model. This can be accomplished in many of the commonly available CAD packages. The model is then exported to the Slicer software via the stereolithography (STL) format. This format reduces the part to a set of triangles by tessellating it. The advantage of the STL format is that most CAD systems support it, and it simplifies the part geometry by reducing it to its most basic components. The disadvantage is that the part loses some resolution, as only triangles, and not true arcs, splines, etc., now represent it. However, the errors introduced by these approximations are acceptable as long as they are less than the inaccuracy inherent in the manufacturing process. Once the STL file has been exported to Slicer, it is then horizontally sliced into many thin sections. These sections represent the two-dimensional contours that the FDM process will generate which, when stacked upon one another, will closely resemble the original three-dimensional part. This sectioning approach is common to all currently available RP processes. Obviously, the thinner the sections, the more accurate the part. The software then uses this information to generate the process plan that controls the FDM machine's hardware.

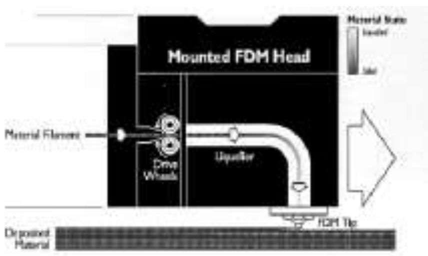


Figure : FDM Machine Hardware

PROCESS CONTROL PARAMETERS:

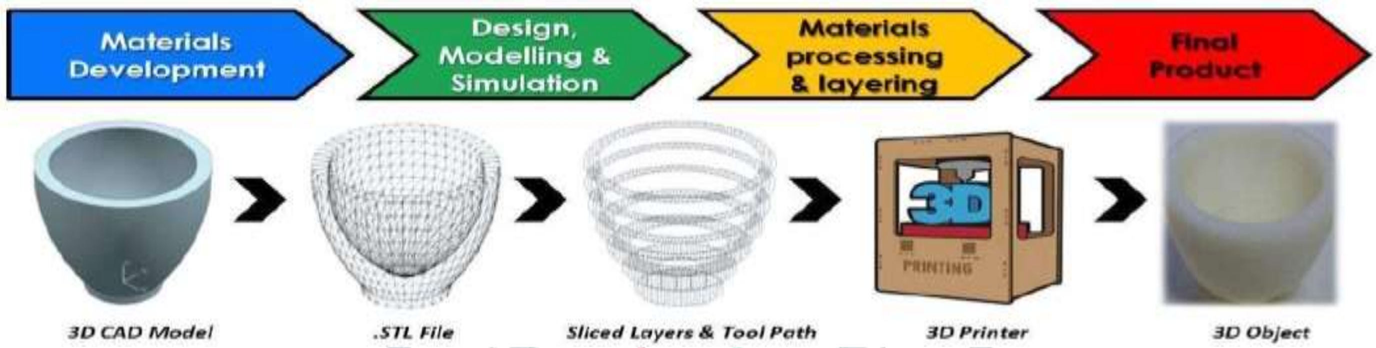
The milling process to be investigated corresponds to 9 different experiments on each three different composition metal alloys. For the GRA, these 9 experiments become 9 subsystems. The influence of these subsystems on the response variable is to be analyzed using GRA technique. Hence, the milling process (system) is assessed by conducting 9 experiments (subsystems) where each experiment is termed as comparability sequence (subsystem).

Bead (or road) width: This is the thickness of the bead (or road) that the FDM nozzle deposits. It can vary from 400 to 100 microns for the T12 nozzle which is currently installed on our 'Global 3D Labs' FDM machine.

Air Gap: This is the space between the beads of FDM material. The default is zero, meaning that the beads just touch. It can be modified to leave a positive gap, which means that the beads of material do not touch. This results in a loosely packed structure that builds rapidly. It can also be modified to leave a negative gap, meaning that two beads partially occupy the same space. This results in a dense structure, which requires a longer build time.

Model Build Temperature: The temperature of the heating element for the model material. This controls how molten the material is as it is extruded from the nozzle.

Raster Orientation: The direction of the beads of material (roads) relative to the loading of the part.



Materials used for 3D printing:

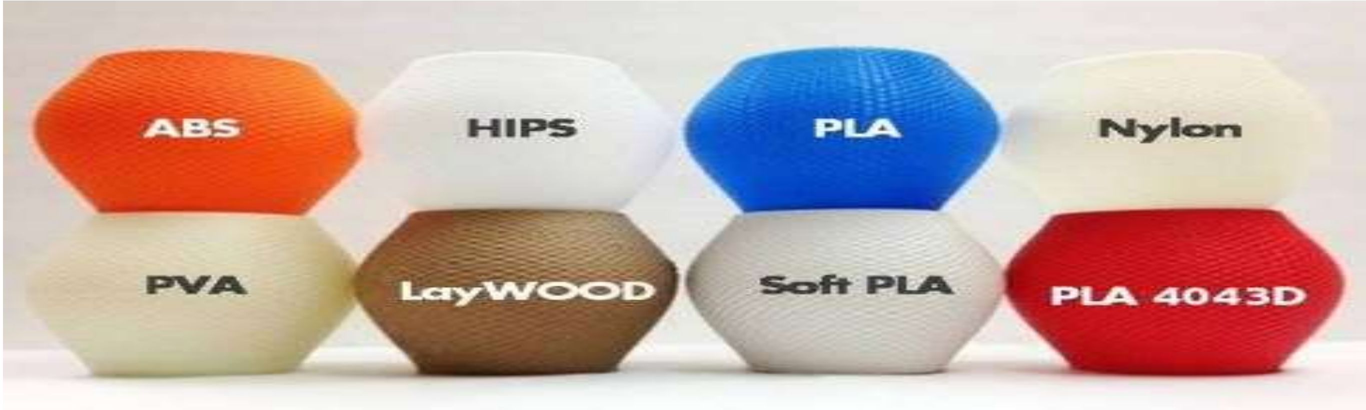
In terms of raw materials that are put into the printing system to create the 3-D objects, there seem to be relatively few limitations on what can be used. Currently, plastics are the most widely used materials in additive manufacturing, and the important ones are listed below:

- **PET** – Polyethylene Terephthalate- generally used to prepare bottles.
- **PET-G** – Polyethylene Terephthalate-Glycol modified- Pet-G is a 3D printing filament where Glycol is added to PET to decrease brittleness
- **CARBON FIBER** – It is a reinforced material used to increase the strength of all 3D printing filaments.
- **CARBON FIBER REINFORCED PET-G** – The added carbon fiber to PET-G will increase the strength to weight ratio of the filament.
- **ABS** - acrylonitrile butadiene styrene or 'lego' plastic – a very common choice for 3D printing
- **PLA** - polylactic acid – Is available in soft and hard grades, is becoming very popular and may overtake ABS in the near future
- **PVA** - polyvinyl alcohol – This is used as a dissolvable support material or for special applications.
- **PC** – polycarbonate – Polycarbonate requires high-temperature nozzle design and is in the proof-of-concept stage.
- **SOFT PLA** - polylactic acid – Is rubbery and flexible, available in limited colors and sources. As 3D printing spreads, may get easy to find.
- **Laywoo-D3**: The wood filament prints easily, similar to PLA, and has a wood smell when printing.

PET - G

Carbon Fiber PET – G

Materials for 3D printing



PROPERTIES OF PET-G

Being a copolymer, Polyethylene Terephthalate Glycol's chemical formula is $(C10H8O4)_n$ and its properties include being transparent with a high gloss surface. It's got a high impact resistance which is similar to polycarbonate and it's also incredibly ductile. PETG has an excellent chemical resistance, is easily thermoformable and is also capable of reducing sound transmissions while also being sterile and recyclable

APPLICATIONS

- Polyethylene Terephthalate Glycol can be used in a variety of applications including for medical and food purposes, electronic devices, covers and even medical braces.
- Printing grade PETG provides excellent printability, laminating characteristics and flexural strength. It's suitable for a range of applications and is now being used to make credit or gift cards because it's a more environmentally friendly alternative to rigid PVC.
- Due to its impact resistance properties, PETG is also being used in thermoforming applications which require deep draws and complex shapes.

USES OF PET-G

- PETG is a clear sheet product, similar to glass and PVC, but is also tough – a property it retains at low temperatures – and fire resistant. It also has a high level of chemical resistance, so it has been approved for use with foodstuffs and in the medical and pharmaceutical sectors
- It is also easy to machine and fabricate and it can be printed on, which makes PETG uses ideal for one of its most common products.
- PETG is ideal because it can be crafted into any shape and any color, but it is still hardwearing.
- PETG is a good all-rounder but stands out from any other filaments due to its flexibility strength temperature and impact resistance which makes it an ideal 3D printer filament to use for objects which might experience sustained or sudden stress.

CARBON FIBER REINFORCED PET-G

When 3D printer filament like PLA, PETG are reinforced with carbon fiber the result is an extremely stiff and rigid material with relatively little weight, very good ductility, impact resistance and higher strength than PLA Carbon Fiber. Such compounds shine in structural applications that must withstand wide variety of end-use environments.

USES OF CARBON FIBER PET-G

Carbonated PETG is mainly used in for Micro air vehicles, RC plans, RC cars and microstructures because of its structural strength and low density

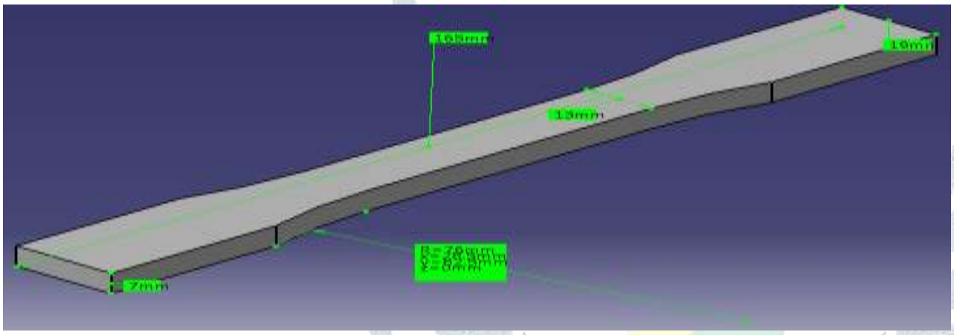
APPLICATIONS

- Musical instruments, including violin bows, guitar picks and pick-guards, drum shells, bagpipe chanters and entire musical instruments such as Luis and Clark's carbon fiber cellos, violas and violins; and Blackbird Guitars' acoustic guitars and ukuleles, also audio components such as turntables and loudspeakers.
- Firearms use it to replace certain metal, wood, and fiberglass components but many of the internal parts are still limited to metal alloys as current reinforced plastics are unsuitable.
- High-performance drone bodies and other radio-controlled vehicle and aircraft components such as helicopter rotor blades.
- Lightweight poles such as: tripod legs, tent poles, fishing rods, billiards cues, walking sticks and high reach poles such as for window cleaning.
- Dentistry, carbon fiber posts are used in restoring root canal treated teeth.
- Railed train bogies for passenger service. This reduces the weight by up to 50% compared to metal bogies, which contributes to energy savings.
- Laptop shells and other high-performance cases.

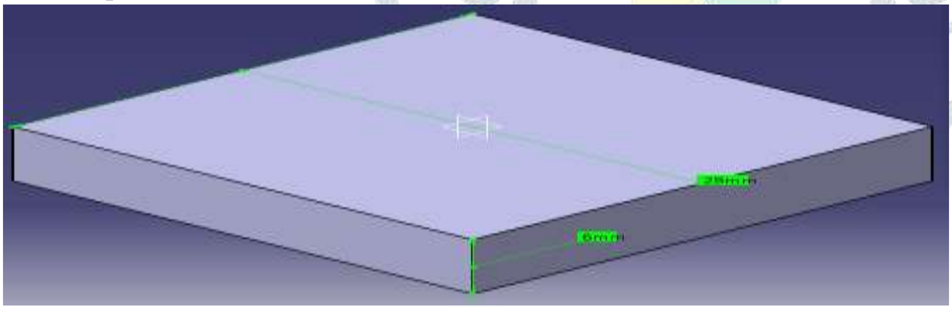
IV. EXPERIMENTAL SETUP:

Fabrication of FDM Parts

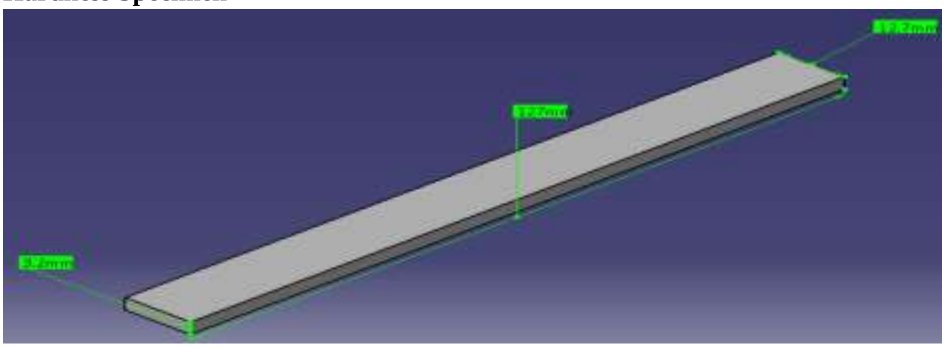
FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. FDM begins with a software process which processes an STL file (stereolithography file format). During the pre-processing stage, the wall thickness of the CAD model was offset so as to account for the metal foil thickness that would be realized during the deposition phase. Figure shows the ASTM standard dimensions for the samples fabricated.



Tensile Specimen



Hardness Specimen



Flexural Specimen

Testing procedure:

Since my work is on testing Carbon fiber reinforced Pet-G for MAV applications we are 3D printing the nine samples of Tensile specimens ASTM D638 of different parameters according to Taguchi L9 and comparing the largest outcome with Pet-G and also testing the carbon fiber reinforced Pet-G with the same parameter by conducting flexural ASTM D790 and shore hardness tests ASTM D785

Evaluation of Mechanical properties

Tensile Test

A tensile test, also known as tension test, is probably the most fundamental type of mechanical test one can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point and yield strength. The testing was performed in accordance with ASTM standard on an Instron Universal Testing Machine of 40KN capacity as shown in the figure 4.5. At first, the test specimens were conditioned at 23 ± 2^0C and 50 ± 5% relative humidity for not less than 40 h prior to test. The width and thickness of each specimen to the nearest 0.025 mm [0.001 in.] was measured. The width and thickness measurements at the centre of each specimen were also made within 5 mm of each end of the gage length. Specimens were placed in the grips of the Instron testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surface was noted and set according to the standard. The grips were tightened evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed. Then, a Calibrated extensometer was attached to the specimen and gage length. The crosshead speed was set to 50mm/min and the machine was started, during testing the inbuilt software records and plots the load-extension curve of the specimen using which the properties such as tensile strength, young modulus and elongation at break were then calculated and recorded.

Figure: Mechanical tests conducted on 20T UTM (Tensile Test)

Specifications of Specimen parameters based on Taguchi L9:

SAMPLE NO.	PARAMETERS		
	PRINT SPEED (mm/sec)	INFILL DENSITY (%)	LAYER HEIGHT (microns)
1	80	80	100
2	100	60	100
3	60	40	100
4	100	80	200
5	80	40	200
6	60	60	200
7	60	80	300
8	80	60	300
9	100	40	300

Table: Specimen parameters based on Taguchi L9

Figure: Tensile specimen samples Before testing

Figure: Tensile specimen samples Before testing

- **Tensile test results for carbon fiber Pet-G:**

SAMPLE No.	ULTIMATE LOAD (KN)	ULTIMATE TENSILE STRENGTH (MPa)
1	2.700	29.466
2	2.700	30.030
3	2.280	25.244
4	2.580	31.174
5	2.340	28.481
6	1.680	20.005
7	2.940	34.629
8	2.280	27.049
9	1.980	23.571

Flexure Testing

The stress–strain behavior of polymers in flexure is of interest to a designer as well as a polymer manufacturer. Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis.

Modulus of Elasticity (Flexural Modulus)

The flexural modulus is a measure of the stiffness during the first or initial part of the bending process. This value of the flexural modulus is, in many cases, equal to the tensile modulus. The flexural modulus is represented by the slope of the initial straight- line portion of the stress–strain curve and is calculated by dividing the change in stress by the corresponding change in strain.

Determination of flexural modulus is important to overcome certain practical problem in measuring tensile strength of thermoplastics in brittle region. Flexural testing determines the strength of the material when a force is applied perpendicular to the longitudinal axis sample. In this section, flexural test was carried out using an Instron UTM Machine

Figure: FLEXURAL SPECIMEN BEFORE TESTING

Figure: FLEXURAL SPECIMEN AFTER TESTING

Mechanical properties of Carbon Fiber Pet-G Flexural Specimen

S.No	Specimen	Load P (N)	L (mm)	3PL	b (mm)	d (mm)	d*d	$2bd^2$	Flexural Strength (N/mm^2)
1	300µ, 80%, 60mm	480	50	72000	13.28	3.26	10.6276	282.27	255.08

Hardness Test

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material. Indentation hardness value is obtained by measuring the depth or the area of the indentation using one of over 12 different test methods.

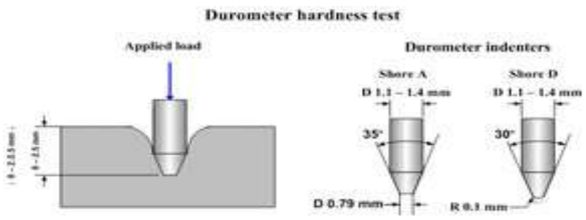


Figure: Diagram of Durometer

Before Testing

After Testing

Mechanical Properties of Carbon Fiber Pet-G Hardness Specimen Samples:

S/NO.	SPECIMEN	SHORE HARDNESS (D)
1	300µ, 80%, 60 mm/sec	52, 52, 53

Table: Shore hardness values

STATISTICAL ANALYSIS:

MINITAB

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was last published 1986, and there has been no significant development since then. Minitab is distributed by Minitab, Inc., a privately owned company headquartered in **State College, Pennsylvania.** Minitab, Inc., also produces other software that can be used in conjunction with Minitab. Quality Trainer is an eLearning package that teaches statistical tools and concepts in the context of quality improvement and Quality Companion is a tool for managing Six Sigma and Lean manufacturing.

TAGUCHI L9

Taguchi methods are statistical methods, or sometimes called robust design methods, developed by **Genichi Taguchi** to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising.

Taguchi's work includes three principal contributions to statistics:

- A specific loss function
- The philosophy of off-line quality control; and
- Innovations in the design of experiments.

DESIGN OF TAGUCHI L9

Design of Taguchi L9 depends mainly on the parameters to obtain optimum condition. The design of Taguchi is shown in the figure below.

Taguchi Design

Design Summary

Taguchi Array	L9(3^3)
Factors:	3
Runs:	9

Columns of L9(3^4) array: 1 2 3

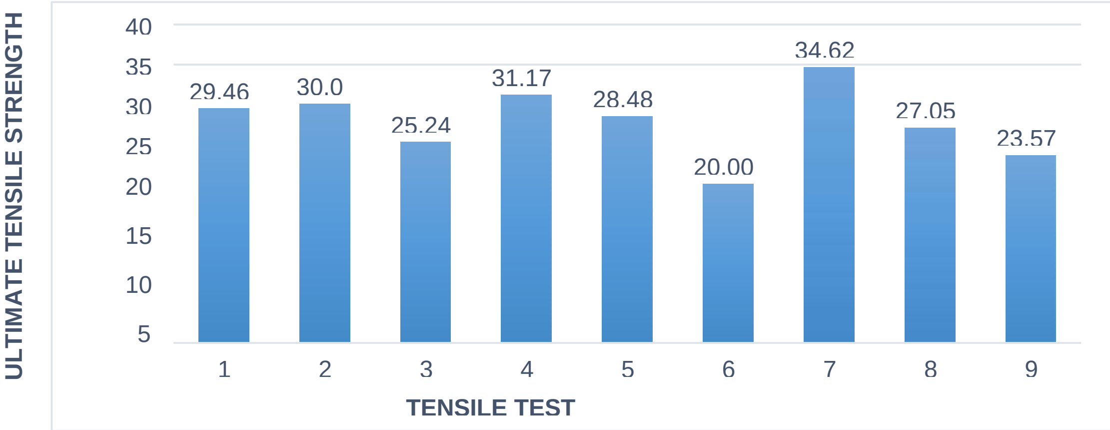
Worksheet 1 ***

	C1	C2	C3	C4
	Print Speed	Fill Density	Layer Thickness	
1	60	40	100	
2	60	60	200	
3	60	80	300	
4	80	40	200	
5	80	60	300	
6	80	80	100	
7	100	40	300	
8	100	60	100	
9	100	80	200	

Table : Design of Taguchi L9

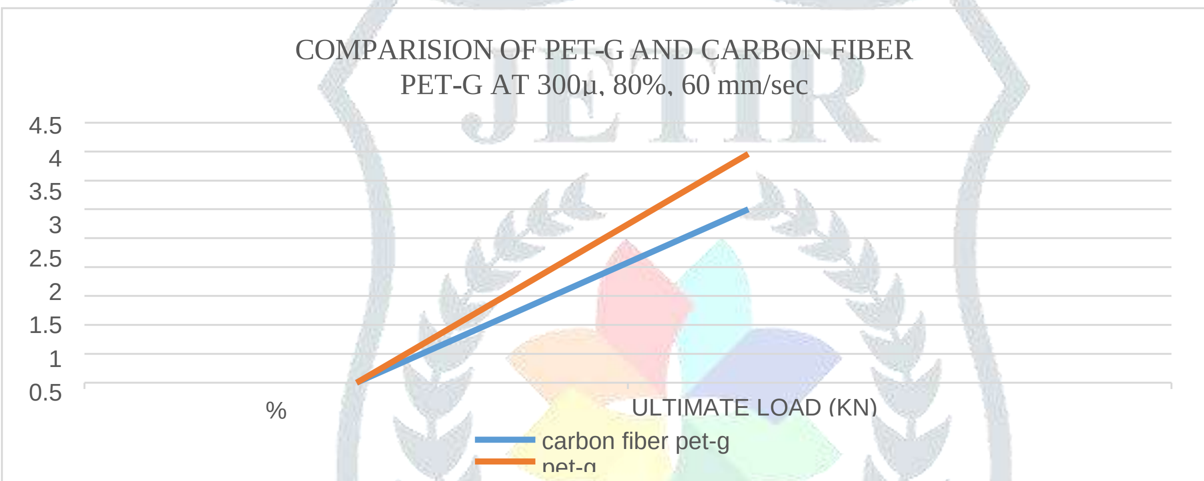
GRAPHS

ULTIMATE TENSILE STRENGTH IN MPa



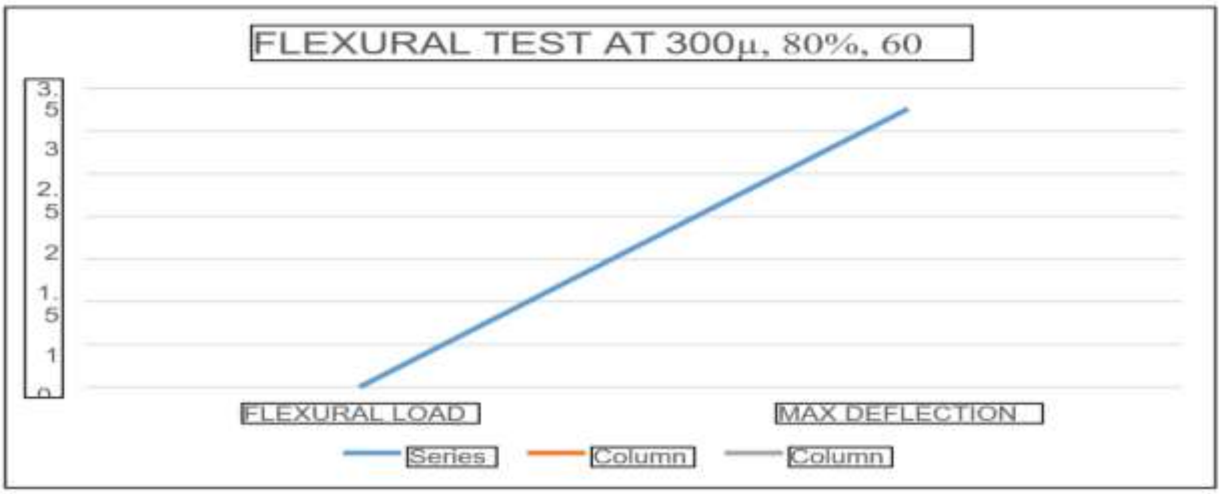
Graph: ultimate strength of tensile specimens

COMPARISION OF ULTIMATE LOAD (KN) OF CARBON FIBER PET-G AND PET-G



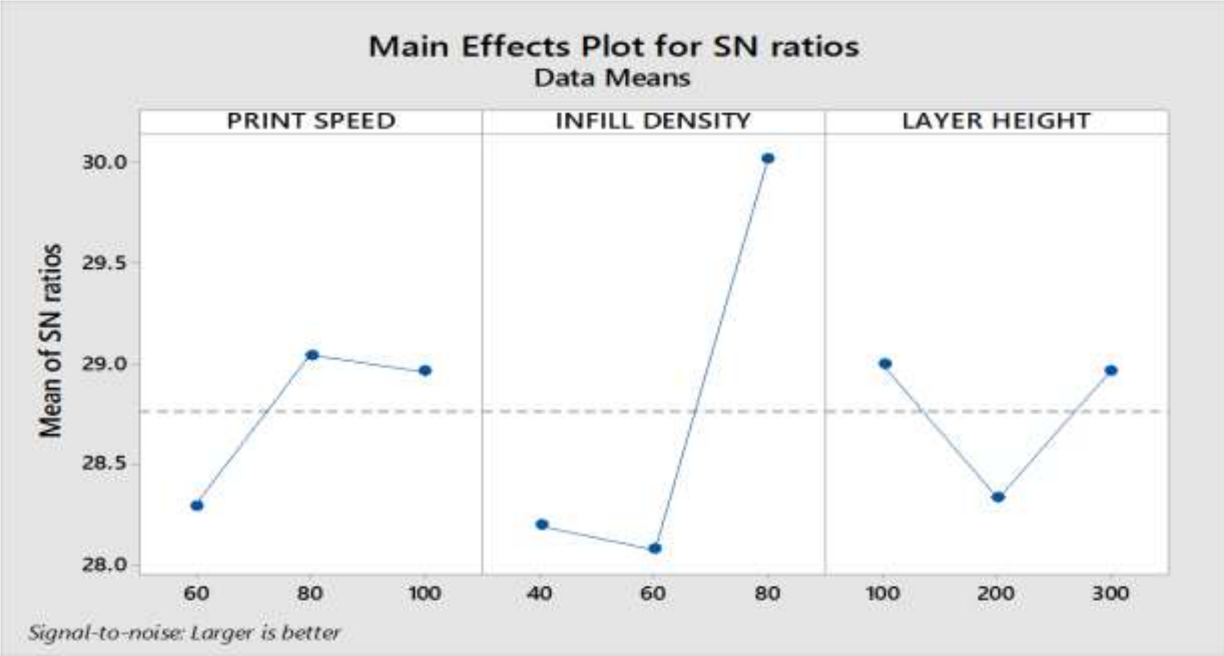
Graph: Comparison of ultimate load in KN

FLEXURAL TEST



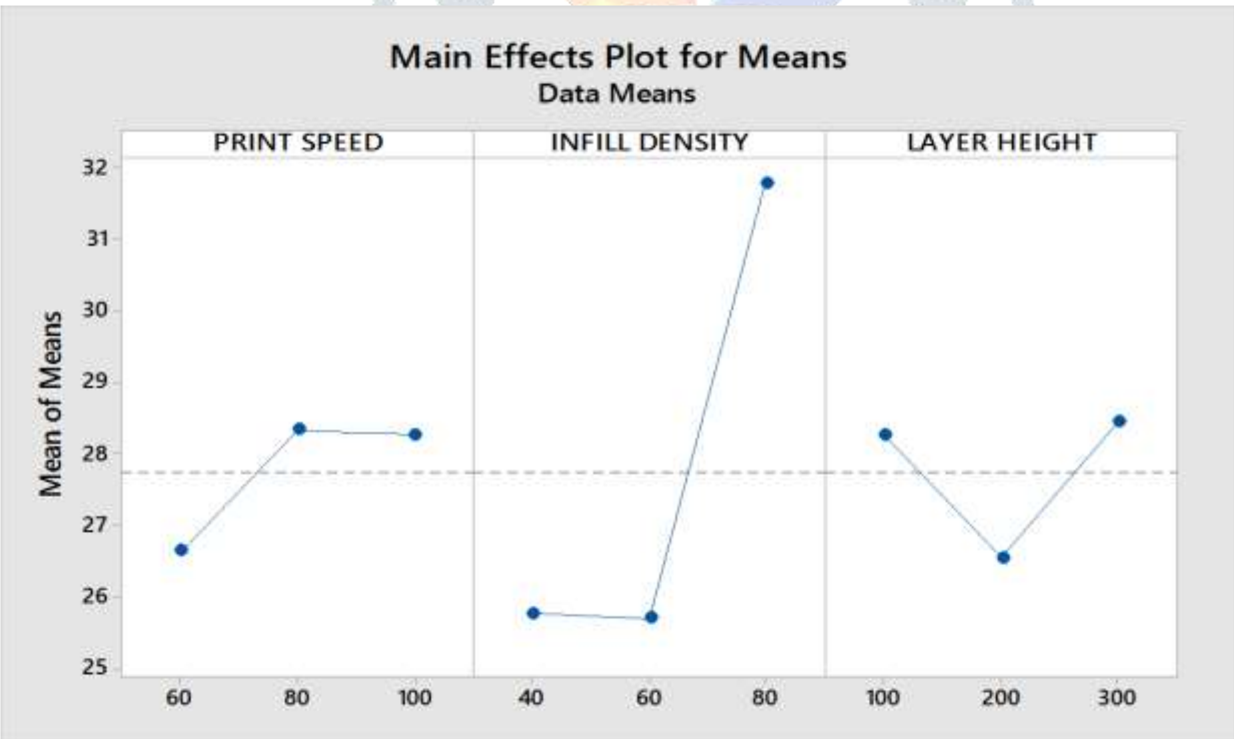
Graph : Flexural test

OPTIMUM CONDITION OBTAINED IN MINITAB 5.4.1STRENGTH TO NOISE RATIO FOR ULTIMATE TENSILE STRENGTH (MPa)



Graph : main effects plot for SN ratio

MEAN OF MEANS GRAPH for ultimate tensile strength (MPa)



Graph 5.5: main effect plot for means

FINAL VALUES OF SN GRAPHS FOR ULTIMATE TENSILE STRENGTH

Minitab 234567.mtw ***

↓	C1	C2	C3	C4	C5	C6	C7
	PRINT SPEED	INFILL DENSITY	LAYER HEIGHT	STRENGTH	ULTIMATE LOAD	SNRA1	MEAN1
2	60	60	200	20.005	1.68	26.0228	20.005
3	60	80	300	34.690	2.94	30.8041	34.690
4	80	40	200	28.481	2.34	29.0911	28.481
5	80	60	300	27.059	2.28	28.6462	27.059
6	80	80	100	29.466	2.70	29.3864	29.466
7	100	40	300	23.571	1.98	27.4476	23.571
8	100	60	100	30.030	2.70	29.5511	30.030
9	100	80	200	31.174	2.58	29.8759	31.174
10							

TABLE: SN RATIO AND MEAN VALUES

V. RESULTS AND DISCUSSION:

Tensile test:

The geometrical data input to the computer is taken from the tensile test configuration according to ASTM D638 standards. The loading and boundary conditions are shown in Figures. The specimen is fixed in the testing machine and the movable jaw is adjusted for the gauge length of 45 mm. The tensile load is gradually applied till the specimen is broken at the average max. Values of 1.68 - 2.98 KN. The load then falls to zero.

Flexural test:

The specimen geometry for 3-point bend test as per ASTM D 790 standard. The specimen is held in the testing machine as a simply supported beam and load is gradually applied at the center. When the applied load reaches ultimate value the specimen breaks and subsequently the load falls to zero.

Shore Hardness Test:

The Shore Hardness method for ASTM D785 Carbon Fiber PET-G measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number. Preliminary test loads (preloads) range from 3 kgf to 10 kgf to 200 kgs. Total test forces range from 15kgf to 150 kgf (superficial and regular) to 500 to 3000 kgf (macro hardness). This test procedure is carried out on a standard block of ASTM D 2240:2003

Figure : All Specimens Before Testing

Figure: All Specimens After Testing

VI. CONCLUSION:

- The common failure in MAVs is "The failure due to impact". The present MAV bodies are printed by using ABS and PLA material. The impact resistance of these materials is less due to their brittleness. PET-G and Carbon reinforced PET-G are used as alternatives for better impact resistance.
- Optimizing the process parameters of PET-G and Carbon reinforced PET-G in Fused Deposition Modeling. The input parameters taken as fill density, print speed, filling shape and layer thickness. A design of experiments are conducted based on Taguchi L9 orthogonal array. The output responses are taken as tensile strength, compression strength and young's modulus of test specimen. Experimental analysis of MAV body by preparing MAV prototype with PET-G and Carbon reinforced PET-G.
- Design of experiments by using Taguchi L9 orthogonal array.
- Preparing of test specimens
- Conducting experimental analysis
- Optimize the process parameters
- Experimental analysis to find mechanical properties

VII. FUTURE WORK:

3D printing, or additive manufacturing, has the potential to democratize the production of goods, from food to medical supplies, to great coral reefs. In the future, 3D printing machines could make their way into homes, businesses, disaster sites, and even outer space. MAV Bodies also printed by using PET-G, Carbon fiber PET-G Material it has ductile nature.

REFERENCES:

- Omar A. Mohamed, Syed H. Masood ,Jahar L. Bhowmik (2016) "Optimization of fused deposition modeling process parameters: a review of current research and future prospects" Advance manufacturing Springer journal ISBN:DOI 10.1007/s40436-014-0097-7
- Fuda Ning , Weilong Cong , Jingjing Qiu b, Junhua Wei , Shiren Wang (2015) " Additive manufacturing of carbon fiber reinforced thermoplastic composites using fused deposition modeling" Elsevier journal on composite materials Part B 80 (2015) 369-378.
- Guoying Dong, Grace Wijaya, Yunlong Tang, Yaoyao Fiona Zhao (2018) "Optimizing process parameters of fused deposition modeling by Taguchi method for the fabrication of lattice structures " Elsevier journal on Additive Manufacturing 19 (2018) 62–72
- Karalekas D and Antonioua K, 2004, "Composite rapid prototyping: overcoming the drawback of poor mechanical properties" Journal of MaterialsProcessing Technology, Vol 153-154, pp.526-530.