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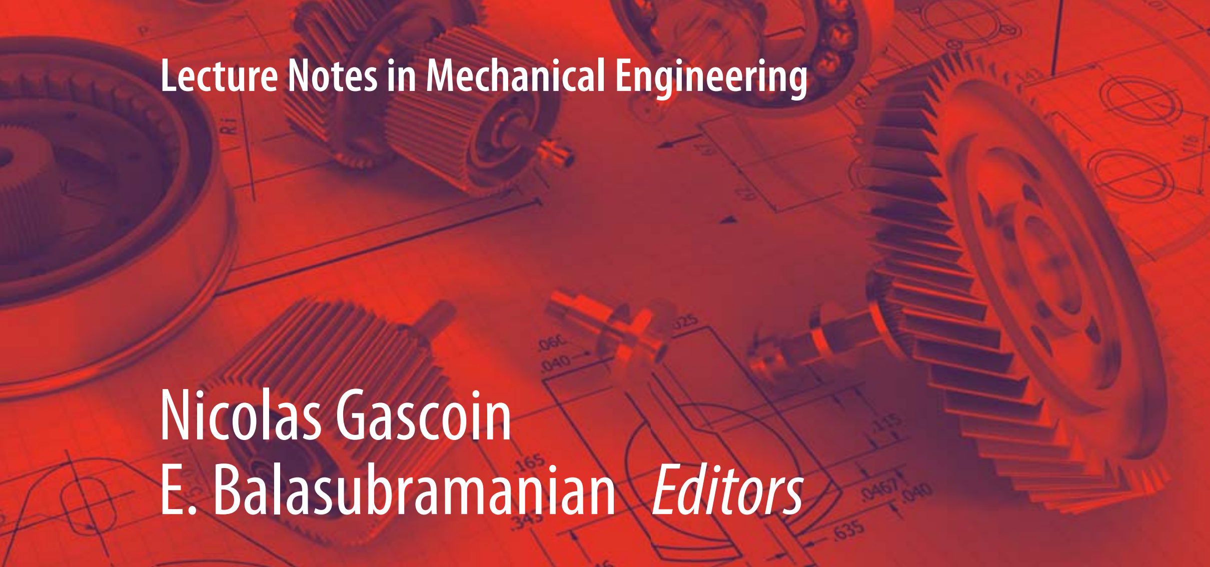

Lecture Notes in Mechanical Engineering

Nicolas Gascoin
E. Balasubramanian *Editors*

Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering

Proceedings of I-DAD 2020

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Editors

Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering

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Preface

Design and development are the aspirations of tomorrow's technologies for aero and auto industries to be alive in the competitive world, where cost-effective solutions, improvements in greenhouse environment, longevity/life cycle, eco-friendly materials and manufacturing, certification and government legislation demands are becoming stringent. The aerospace/automotive industries are looking for prominent solutions to improve their performance in air/road. Both the industries have come to symbolize the essence of utilizing the state-of-the-art and cutting edge technologies for satisfying the customer demands. Perhaps more than any other single icon, it is associated with a desire for independence and freedom of movement; an expression of economic status. For the next decades, they are marching towards a new concept designs, analysis and manufacturing technologies, where more swing is for improved performance through specific and/or multifunctional linguistic design aspect to downsize the system, improve the weight-to-strength ratio, fuel efficiency, make better the operational capability at room and elevated temperatures, reduce wear and tear, NVH aspects while balancing the challenges of beyond Euro VI emission norms, greenhouse effects and recyclable materials. The conference covered the research areas such as additive manufacturing, aerodynamics, CAD, CFD, cryogenics, design engineering, environment, finite element method, fuels and energy source, hybrid and electric vehicles, instrumentation and sensors, modeling and simulation, manufacturing, materials, NVH, optimization technologies, product development, propulsion systems, quality, reliability and durability, safety and risk assessment, sustainable manufacturing, UAVs and autonomous systems and vehicle dynamics and control. The conference aimed at addressing these issues of tomorrow where academia—industry—R&D partnerships and collaborative programs can be shared and implemented. The organizers of the 4th International Conference on Innovative Design, Analysis and Development Practices in Aerospace and Automotive Engineering (I-DAD 2020) wish to provide a platform for deliberations on design engineering, numerical methods, analysis/optimization techniques, life cycle engineering, system engineering, configuration managements, advanced materials, novel manufacturing/prototyping, vibration and health monitoring, propulsion system and quality and reliability in the aerospace and automotive fields. The response to the conference was overwhelming on both national and international fronts.

Chennai, India

Prof. Nicolas Gascoin
Prof. E. Balasubramanian

Contents

About the Editors

Dr. Nicolas Gascoin is Director at INSA Centre Val de Loire (Institut National des Sciences Appliquées, ex ENSI Bourges), France. He holds a Ph.D. in the area of Scramjet cooling by endothermal reactive fuel from MBDA–EADS, Bourges (France). He has published more than 50 papers in international, peer-reviewed journals and attended 90 international conferences. He has also served as an advisor for postdoc and research engineers since 2007. Dr. Gascoin has coordinated numerous major research projects

Dr. E. Balasubramanian completed his Ph.D. in Robotics and Control at Concordia University, Montreal, Canada. He has more than fifteen years of research experience and conducted various funded projects under the aegis of DST, DRDO and ISRO, Government of India. He has collaborated with scientists in Taiwan, Canada and Korea in the development of flapping and rotary wing UAVs for diverse applications, including inspection of bridges, heritage structures, telecom towers, power line cables, monitoring of traffic signals, environment and water quality inspections. He also developed a test rig to measure aerodynamic forces of ornithopters and powder-based additive manufacturing systems. He has won several national and international competitions. He is in editorial board member and reviewer for various journals. His research interests include UAVs, robotics, rapid prototyping, control and sensors with online data acquisition. He has published more than 100 research papers, two books and filed many patents.

Development of DLP-Based Stereolithography System

Baban Suryatal, Suhas Deshmukh, and Sunil Sarawade

Abstract A low-cost stereolithography (STL) apparatus was developed to produce highly precise, three-dimensional (3D) structures from broad selection of functional materials, especially photopolymer resin. The developed stereolithography apparatus (SLA) utilizes focused light beam of wavelength range (300–700 nm) coming from the DLP projector and passing through the objective lens over the surface of a photocurable resin, which undergoes photopolymerization and forms solid structures. The photopolymer used in this STL system was polyethylene glycol di-acrylate and photoinitiator was Irgacure 784. The Creo 3.0 software was used for modelling of 3D object. A special MATLAB code was developed for slicing of the 3D CAD model. The Creation Workshop software was used to control the z-stage motion with the help of Arduino microcontroller, stepper motor, and ball screw. It also controls time period to display the sliced images through DLP projector and settling period. The experiments were successfully performed to built hexagonal cross-section and pyramid objects with 0.1 mm curing depth and two seconds curing time. The pyramid object with maximum 120 numbers of layers with 12 mm maximum dimension along Z-axis was build.

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Keywords Stereolithography (STL) · Digital light processing (DLP) projector · Photopolymer · Photoinitiator

1 Introduction

Nowadays, rapid prototypes of the different objects are required before its actual manufacturing because one can improve the design before its actual manufacturing. This technology is very fast growing one and can be applicable to all the fields, i.e., engineering as well as non-engineering. The present 3D printers available in the market are very costly one. In this research paper, a low-cost stereolithography apparatus (SLA) was developed which will be affordable to anybody with low cost of printing. Ikuta et al. [1] introduced micro stereolithography technology and also proposed a means of applying micro stereolithography in mass-production using an optical fiber array so that multiple microstructures could be fabricated in a single process. Bertsch et al. [2] developed a micro stereolithography apparatus employing a pattern generator in which a UV laser and dynamic LCD pattern generator were used to generate the cross-section of a 3D structure. While the substrate did not move in the *x*–*y*-direction in the liquid photopolymer, an LCD pattern generation system was necessary. Itoga et al. [3] developed maskless photolithography device by modifying liquid crystal display (LCD) projector optics from magnified to reduced projection. But they arise problems in jagged pattern boundaries due to the liquid crystal panel structure and collapse pattern of the boundary divided on divisional exposure using the auto-XY stage. Hadipoespito et al. [4] developed DMD-based UV microstereolithography system for fabricating 2D and 3D microparts providing reasonable curing speed and good resolution at a low cost. In this method, process optimization is needed to improve the quality of fabricated microparts. Zhou and Chen [5] presented a novel AM process based on the mask video projection. For each layer, a set of mask images instead of a single image is planned based on the principle of optimized pixel blending. Compared to fused deposition modelling (FDM) machines, machines for DLP stereolithography are expensive and thus not available to a broad range of users as it is the case with FDM 3D printers. Gandhi et al. [6] analyzed various optical scanning schemes used for MSL systems by optical simulations and experiments. The mechanical design of the scanning mechanism is carried out to meet requirements of high speed and resolution. The system integration and investigation in process parameters are carried out and large microcomponents with high resolution are fabricated. Valentincic et al. [7] conclude that constrained surface (illumination through a transparent bottom of the vat) gives better 3D printing accuracy compared to free surface (illumination of the photopolymer surface). The all above-described stereolithography apparatus are very costly which are not affordable to common- or medium-sized industries or vendors who can build their prototypes with a cheaper cost. Therefore, development of a low-cost SLA is necessary and which was the goal of this research.

2 Experimental Setup

2.1 *Stereolithography Apparatus (SLA)*

A low-cost stereolithography apparatus (SLA) was developed to produce highly precise, three-dimensional (3D) structures from broad selection of functional materials, especially photopolymer resin. The experimental setup is shown in Fig. 1. The developed stereolithography apparatus (SLA) utilizes focused light beam from DLP projector and then through the objective lens over the surface of a photocurable resin, which undergoes photopolymerization and forms solid structures. The lamp of the modified DLP projector works as light source and DMD chip in the DLP projector works as a dynamic pattern generator. The color wheel of the DLP projector was filtering most of the UV light out. Therefore, glass portion of the color wheel was removed so that maximum UV light should focus by the projector which was our requirement for solidification of the photopolymer. Infocus makes DLP projector with display resolution 1024 × 768 was used.

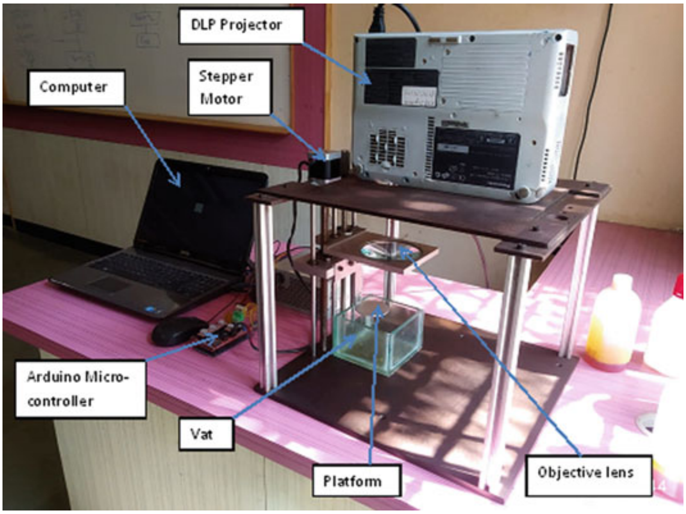

Fig. 1 Experimental setup

The photopolymer used in this experimentation was polyethylene glycol diacrylate and 2% Irgacure 784 as a photoinitiator was added in the photopolymer. The maximum absorbance of the photopolymer was in the range of 315–340 nm. The stepper motor was used to rotate the ball screw which moves the Z-stage platform up and down. The sliced layer image was focused on platform through projector and objective lens. The sliced image consists of black and white portion; the photopolymer on the platform with white portion of the focused image was solidified. The Creo 3.0 software was used for modelling of 3D CAD model. A special MATLAB code was developed for slicing of the 3D CAD model and this sliced 3D CAD model was imported into the Creation Workshop software which was used to control the focusing time period of sliced images through DLP projector. The Creation Workshop software also controls the motion of the Z-stage through Arduino MEGA 2560 microcontroller and NEMA 17 bipolar stepper motor. Finally, the different shape objects are built by curing the aforementioned photocurable resin. The digital microscope was used to measure the dimensions of the built parts. The overall cost of the developed SLA is two lac thirty five thousand Indian Rupees only.

2.2 Slicing of 3D CAD Model

The 3D CAD model of the object which was to be built by using STL process was developed with the help of CREO 3.0 software and then it was saved in .STL file format. The .STL file consists of an unordered list of triangular facets that represent the outside skin of a part. The triangular facets are described by a unit normal vector and a set of X, Y, and Z coordinates for each of the three vertices. The unit vectors indicate the outside of the part. Since the STL model consists of triangular facets, it is an approximate model of the accurate CAD data. .STL file is a simple solution for representing 3D CAD data and it provides small and accurate files for data transfer for specific shapes [8]. After generating the .STL file of the 3D CAD model, then it was sliced into a number horizontal cross-sections with the help of specially developed MATLAB code by using ray tracing method [9]. The sliced CAD model in MATLAB window is shown in Fig. 2. The sliced CAD model was imported in Creation Workshop software and the sliced layers were focused one by one at required time interval with the help of DLP projector through objective lens on the Z-stage platform and finally, the 3D object was built.

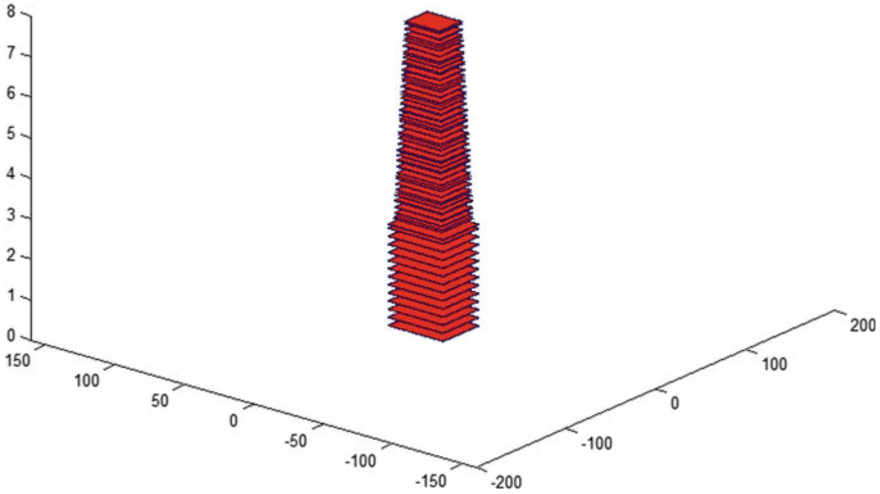

Fig. 2 Sliced CAD model in MATLAB

2.3 ARDUINO Programming

In the Z-stage, we have to control the linear movement of the platform with the help of stepper motor and ball screw. The stepper motors rotational motion was transformed into linear motion with help of ball screw coupled with motor shaft. The rotational movement of the stepper motor was controlled with the help of special Arduino program. The program mainly consists of various commands and statements to control the various parameters like speed, time delay, etc. With the used ball screw and stepper motor, the Z-stage can move with 0.005 mm minimum distance. The Arduino microcontroller with stepper motor was interfaced with Creation Workshop Software to obtain desired motion of Z-stage.

3 Experimental Results and Discussions

The experiments were performed on objects with hexagonal cross-section and pyramid objects with 0.1 mm curing depth along Z-axis. The trials were performed with different exposure time and settling period. The exposure time was varied from 10 to 1 s and it was observed that the objects were best cured for 2 s curing time. The pyramid object with 120 numbers of layers with 12 mm dimension along Z-axis was cured. The maximum area 18 mm × 16 mm of pyramid object along X-Y plane was cured. The resolution in Z-axis of 0.25 mm creates a fairly coarse surface for medium-sized parts, but for larger models, the layer steps are not too noticeable due to the relative size of larger parts. A resolution of 0.1 mm provides a more favorable surface finish for medium and small parts [10, 11]. Therefore, experiments were performed with 0.1 mm curing depth along Z-axis. For DMD-based SLA, the maximum model size obtained with 0.1 mm minimum layer thickness in the available literature was 60 mm × 80 mm [11]. Therefore, maximum exposure area of 55 mm × 45 mm in our SLA shows the good agreement to build medium-sized parts. It was observed that as the curing time decreases, the percentage error between the 3D CAD model dimensions and build dimensions was also decreases. The maximum and minimum percentage errors for hexagonal cross-section object were 9.43 and 2.0, respectively. The maximum and minimum percentage errors for pyramid object were 4.5 and 1.77, respectively. The minimum percentage error was observed for 2 s curing time. The maximum percentage error between the CAD models and build components dimensions is also below 10% which shows the good agreement with the results available in the literature [10, 11]. Observed that the resolution of the build components depends upon software imposed parameters like width compensation, .STL file resolution, layer thickness, z compensation, and STL process parameters like light beam size and intensity, light beam focus depth, and layer thickness [12]. The experimental test data for hexagonal cross-section and pyramid objects are given in Table 1. The cured objects are shown in Figs. 3 and 4.

4 Conclusions

A low-cost stereolithography apparatus (SLA) was successfully developed to built 3D components. The trials were performed with different exposure time and settling time. The exposure time was randomly varied from 10 to 1 s and it was observed that the objects were best cured by 2 s curing time. The maximum and minimum percentage errors observed were 9.43 and 1.77, respectively. The percentage error was minimum for 2 s curing time. The pyramid object with maximum 120 numbers of layers with 12 mm dimension along Z-axis was built in 11.0 min. The maximum area 18 mm × 16 mm of pyramid object along X-Y plane was cured. The maximum exposure area obtained in X-Y plane was 55 mm × 45 mm. The objects were built with 0.1 mm curing depth due to limitations of the experimental setup. It is necessary to perform the experiments with values lower than 0.1 mm curing depth so that resolution of object along Z-axis will be improved.

Table 1 Experimentation data of built objects

Object cross-section	Measuring scale	Dimensions (in mm)			Layer thickness (mm)	Number of layers	Exposure time (s)	Settling period (s)	Build time (min)
		x	y	z					
Hexagon (7 mm side)	CAD model	14	14	10	0.1	100	2.0	3.5	9.17
	Built object	15.32	14.28	10.64					
	% Error	9.43	2.0	6.4					
Pyramid	CAD Model	18	16	12	0.1	120	2.0	3.5	11.0
	Built object	17.68	16.72	11.72					
	% Error	1.77	4.5	2.33					

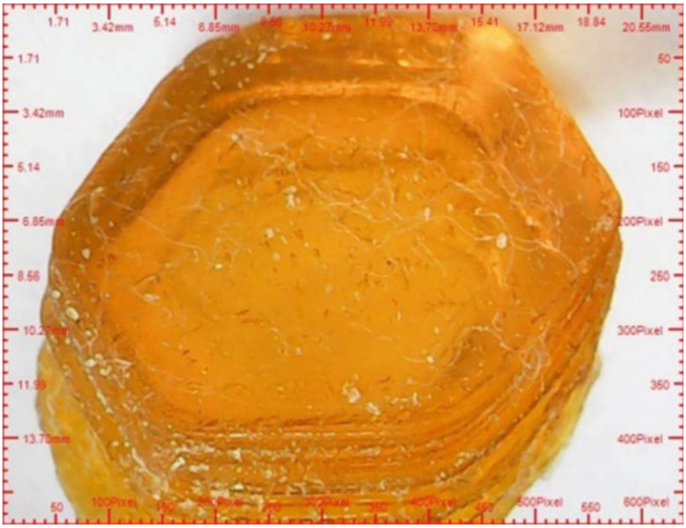

Fig. 3 Hexagonal cross-section object

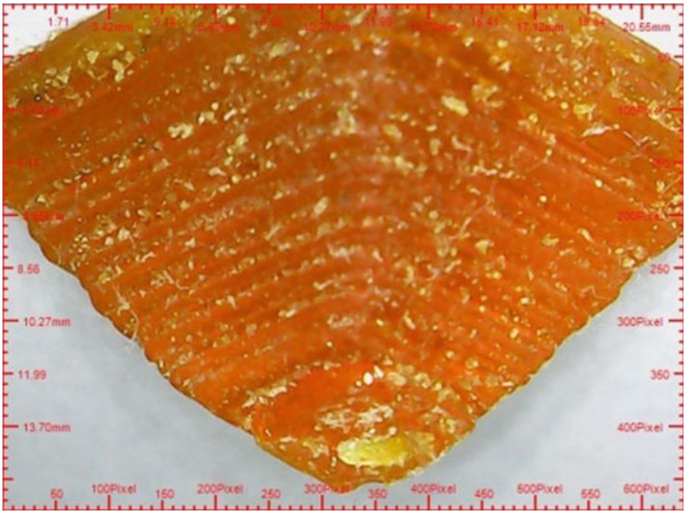

Fig. 4 Pyramid object

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ANN Validation of Biodiesel Synthesis Optimization using Heterogeneous Catalyst (SiO_2)

Satish A. Patil[1,2] and R. R. Arakerimath[3*]

DOI: 10.9734/bpi/rder/v12/5938D

ABSTRACT

Biodiesel is a renewable, ecofriendly fuel that can provide comparable engine performance. Karanja oil is made in this experiment using a transesterification process with SiO_2 as a heterogeneous catalyst. It is investigated utilising five separate parameters and their respective levels. The orthogonal arrays are fixed using Minitab, and the Taguchi method is utilised to study the interaction impact for the transesterification reaction. Molar ratio, catalyst concentration, reaction temperature, reaction time, and stirring speed are the five variables that affect biodiesel yield. The impact of these variables has been investigated on a limited scale. Experimentally biodiesel yield obtained is 77% at optimum conditions are 20% molar ratio, 3% SiO_2 catalyst addition, 65ºC reaction temperature, 180 min reaction time and 500 rpm stirring speed. Minitab results are compared here with ANN results using script by analytically as well as graphically.

Keywords: Transesterification; biodiesel; SiO_2; Heterogeneous catalyst.

1. INTRODUCTION

Diesel fuels are utilized in various zones and contribute to the economies of the countries. Alternative fuels are required due to a rise in environmental consciousness and dwindling petroleum reserves [1]. The ongoing requirements for fuel in meeting the ever-growing demand in commercial sector have pushed researchers in finding and optimizing the production of biofuels from cheap sources, enabling for a sustainable production [1]. The properties like non-toxic, degradability, less carbon monoxide emission, particulate matter and unburned hydrocarbons, the biodiesel has gained an international focus as an alternative to diesel fuel [2]. The conventional compression engine does not require any modification to use the biodiesel as fuel [3]. Improvisation of the biodiesel production by employing heterogeneous catalyst and its optimization is the best way to mitigate the growing concern with the traditional feedstocks and their prices [4].

The yields of Karanja oil biodiesel were obtained by 25 different sets of different experimental conditions and noted. All experiments were performed as per array obtained by Taguchi method under the different experimental conditions as mentioned here.

The analysis of the results has done by Taguchi method using Minitab for optimization of input parameters. The graphs namely main effect plots, interaction plots, regression plot, and mathematical model have obtained during the analysis [5]. The ANN script has written for obtaining results. The yield values obtained by Taguchi array experimentation and obtained by ANN are compared. The graphical and analytical comparative analysis has done. The results obtained by Minitab experimentation are validated by ANN.

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2. OPERATING CONDITIONS

During the Transesterification process for biodiesel production from Karanja oil using heterogeneous catalyst the effect of different input parameters is studied as follows [4].

1) Variation of Molar Ratio. (MR)
2) Effect of Percentage of catalyst.(CP)
3) Effect of Temperature of Process/reaction.(PT)
4) Effect of Stirring Speed of reaction.(SS)
5) Effect of Reaction Time of reaction. (RT)

The range of operating conditions for each parameter has as follows.

Table 1. Optimizing parameter conditions

A:MR	**B: CP**	**C: PT**	**D: RT**	**E:SS**
%	**%**	**ºC**	**min**	**rpm**
A1 = 5	B1 = 1.5	C1=55	D1 = 60	E1 =300
A2 = 10	B2 = 2.0	C2=60	D2 = 90	E2 = 400
A3 = 15	B3 = 2.5	C3=65	D3 = 120	E3 = 500
A4 = 20	B4 = 3.0	C4=67	D4 = 150	E4 = 600
A5 = 25	B5 = 3.5	C5=70	D5 = 180	E5 = 700

3. EXPERIMENTAL RESULTS WITH SiO_2 AS A CATALYST

Initially the esterification process is done, the color of Karanja oil after esterification changed from deep brown to reddish yellow. The transesterification process produces methyl ester (Karanja oil biodiesel) and glycerol form upper and lower layers respectively. Due to more density of glycerin, it was settled at bottom. The catalysts and unused methanol were in the lower glycerol layer. The results shown that, using SiO_2 catalyst the biodiesel production has a considerable potential.

Twenty-five numbers of experiments for transesterification process were conducted using Karanja oil with methanol under different conditions of reactions to produce biodiesel. Input parameters and % of yields were noted. The sample readings are given below [4,5].

Design details
Array obtained by Taguchi Method L25 (5^5)
Factors: Five numbers
Runs: Twenty five
Columns of L25 (5^6) array: 1 2 3 4 5

Table 2. Sample reading of Yield obtained and SNRs

MR	**CP**	**PT**	**RT**	**SS**	**Yield %**	**SNRA1**	**SRES**
5	1.5	55	60	300	50	33.9794	-0.06531
5	2	60	90	400	52	34.3201	-1.24764
10	3.5	55	90	500	72	37.1466	1.83866
15	3	55	120	700	68	36.6502	-0.5516
15	3.5	60	150	300	73	37.2665	0.16741
20	2.5	55	150	400	67	36.5215	-0.94569
20	3	60	180	500	77	37.7298	1.62962
20	3.5	65	60	600	74	37.3846	-0.4575
25	1.5	70	150	500	68	36.6502	0.85144

The above table gives the optimal values of input parameters for maximum biodiesel yield because of high value of SN ratio. The biodiesel yield obtained experimentally at optimum conditions are 20% molar ratio, 3% SiO_2 catalyst addition, 65ºC reaction temperature, 180 min reaction time and 500 rpm stirring speed is 77%.

4 TAGUCHI ANALYSIS WITH SiO_2 CATALYST

Taguchi Analysis: yield % versus Molar Ratio %, Catalyst ... reaction Speed [5,6,7]

Signal to Noise Ratios: Larger is better

Main Effects on yield by SN ratio for Individual Parameter: For examine differences between level for one or more factors the main effect plot is used. The graphs shows the response mean for each factor level [1].

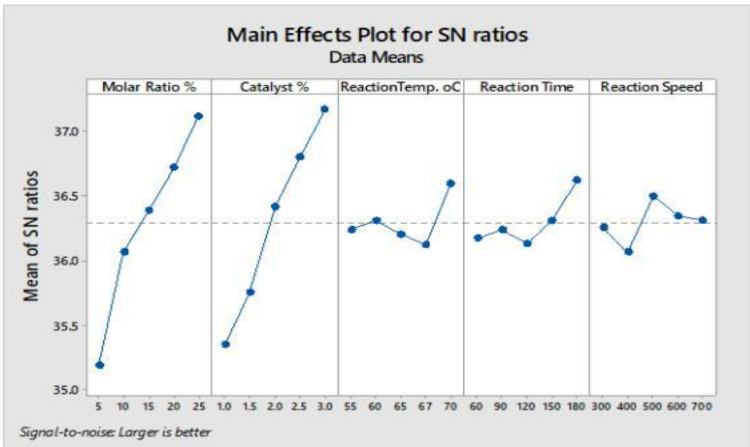

Fig. 1. Main effects Plot for SN ratios

This Fig. 1 shows that, the two graphs are steeper than others. First is the mean of S/N ratios vs molar ratio and second is the mean of S/N ratios vs. catalyst%. So, it is concluded that the two parameters affecting the yield mainly are the molar ratio and catalyst %. The effects of other three parameters can be neglected.

Interaction Plot for SN ratios: Main effects were generally focused by Taguchi method, but suspected interactions are important to test. To measure whether the effect of one factor on response characteristic depends on the level of other the interaction plot is used [1].

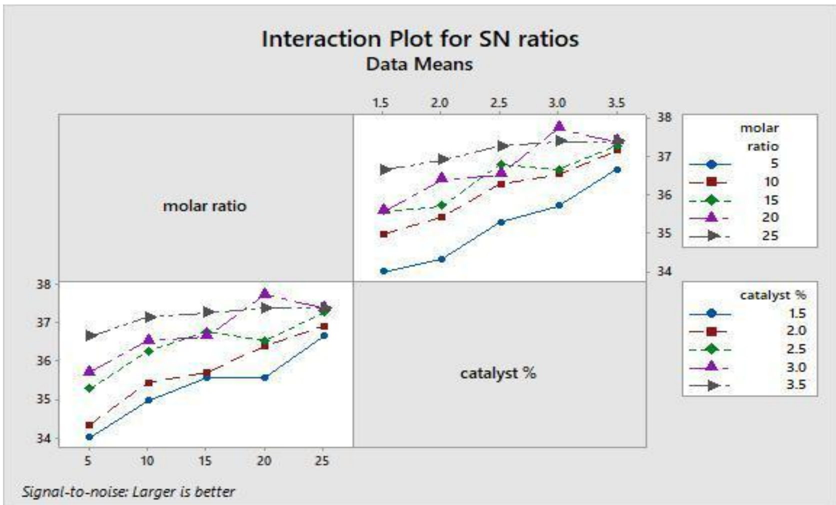

Fig. 2. Interaction Plot for parameter A and B (For molar ratio and Catalyst %)

Simultaneously the interaction plots shows, the variation of yield with effect of molar ratio and catalysts are as shown in Fig. 2. This shows that the yield has maximum value for 20 % molar ratio and catalyst 3%.

5. REGRESSION ANALYSIS FOR SiO_2

Regression Analysis: yield % versus Molar Ratio %, ... , Reaction Speed Analysis of Variance [5,7].

Table 3. Analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	1165.96	233.191	42.00	0.000
Molar Ratio %	1	544.50	544.500	98.08	0.000
Catalyst %	1	598.58	598.580	107.82	0.000
Reaction Temp. ^{0}C	1	1.66	1.657	0.30	0.591
Reaction Time	1	19.22	19.220	3.46	0.078
Reaction Speed	1	2.00	2.000	0.36	0.555
Error	19	105.48	5.552		
Total	24	1271.44			

Model Summary: R square value in model summary provides the measure of, how perfect the model is fitting with the actual data. R square value 91.70% shows that the obtained model is fitted to actual data.

Table 4. Summary of Model

S	R-sq	R-sq (adj)	R-sq (pred)
2.35622	91.70%	89.52%	86.30%

Regression Equation: It is a statistical model that determine the specific relationship between the input and output parameters. It gives the outcome with a relatively small amount of error.

$$\text{Yield \%} = 35.39 + 0.6600\ A + 6.920\ B + 0.0484\ C + 0.0207\ D + 0.00200\ E$$

6. VALIDATION OF EXPERIMENTAL RESULTS

Table 5. Sample Readings of Comparison of Yield by Experimentation and ANN for SiO_2

MR	CP %	PT	RT	SS	Yield %	ANN	Error	Error %
5	1.5	55	60	300	50	49.97	0.03	0%
5	2.5	65	120	500	58	58.64	-0.64	-1%
5	3.5	70	180	700	68	68.00	0.00	0%
10	1.5	60	120	600	56	54.17	1.83	3%
10	2	65	150	700	59	58.47	0.53	1%
10	2.5	67	180	300	65	65.00	0.00	0%
15	2	67	60	500	61	61.32	-0.32	-1%
15	3.5	60	150	300	73	71.29	1.71	2%
20	1.5	67	90	700	60	61.15	-1.15	-2%
20	2	70	120	300	66	65.77	0.23	0%
25	1.5	70	150	500	68	67.65	0.35	1%
25	3	65	90	300	74	73.04	0.96	1%

Comparison of Yield obtained by Experimentation and ANN for SiO_2:

The graphical comparative study of yield obtained by experimentation and ANN is as follows:

The graphical comparison of yield obtained by experimentation and ANN is appearing in Fig. 3. The values of yield obtained by experimentation, by ANN, the difference in these values, and also the % errors are given in Table 5. There is a very small difference between these values and% errors are also very small. So, results obtained by Taguchi method are validated by ANN.

Regression Plots: The normal probability plot is a graphical tool for comparing a data set with the normal distribution. A straight line in this plot shows the data fit a normal probability distribution. There are very low residual values and all residuals obtained are almost along the line.

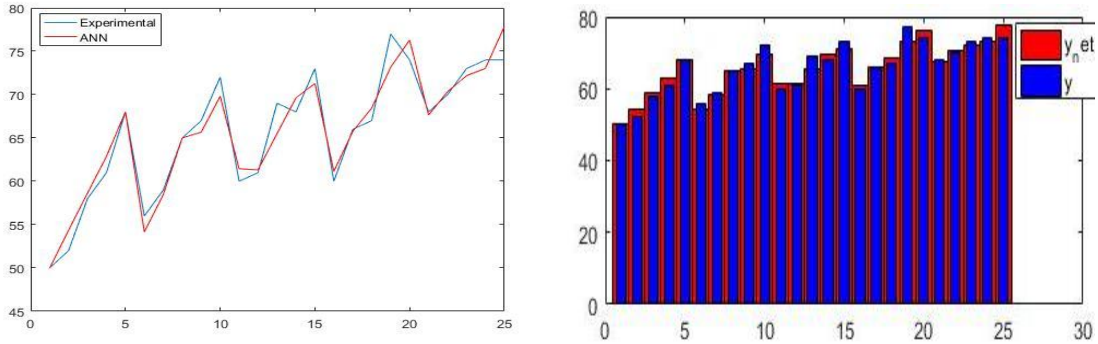

Fig. 3. Comparison of Yield by Experimentation and ANN for SiO_2

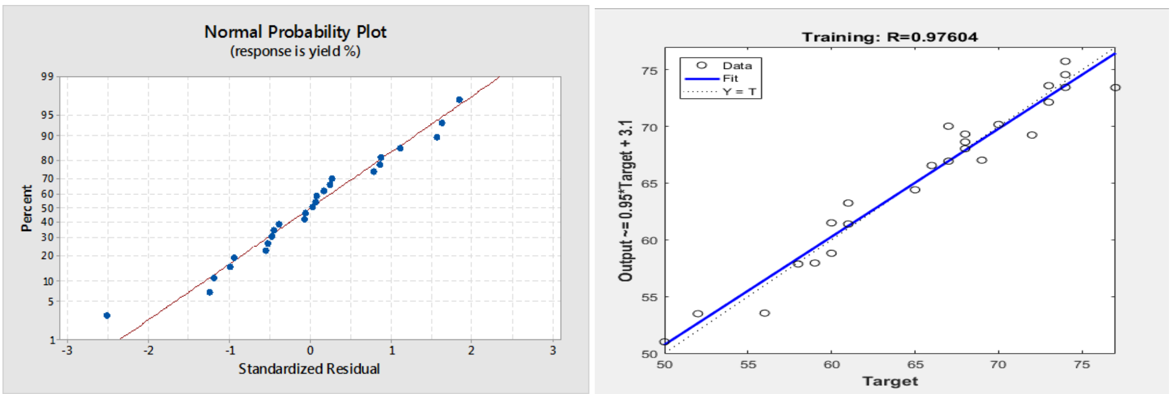

Fig. 4. Comparison of Regression plots by Minitab and by ANN for SiO_2

The R-square value for this regression is 91.70%. The regression plot obtained by ANN is compared with the Minitab regression plot. There are very low residual values and all residuals obtained are also along the line. There is a similarity in these plots, hence results are validated.

7. CONCLUSION

The analysis of optimizing the transesterification process has been carried out by Taguchi method for production of biodiesel from Karanja oil using SiO_2 as a heterogeneous catalyst. The results by experimentation through Minitab have validated by ANN (Artificial Neural Network), the conclusions are;

1) The biodiesel yield obtained experimentally is 77% at optimum conditions are 20% molar ratio, 3% SiO_2 catalyst addition, 65ºC reaction temperature, 180 min reaction time and 500 rpm stirring speed.
2) Main effective plot is concluded that the two parameters affecting the yield mainly are the molar ratio and catalyst %.
3) From interaction plot the yield has maximum value for 20 % molar ratio and catalyst 3%.
4) R square value 91.70% shows that the obtained model is fitted to actual data.
5) There are very small errors between the yields obtained by experimentation and by ANN.
6) The regression plot obtained by Minitab is similar to ANN regression plot.
7) In this way, various results obtained by Minitab have validated by ANN.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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DISCLAIMER
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