Study of parametric optimization of fused deposition modelling process using response surface methodology

A thesis submitted in partial fulfilment of

the requirements for degree in

Bachelor of Technology

in

Mechanical Engineering

By

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA

CERTIFICATE

This is to certify that the thesis entitled *Study of parametric optimization of Fused Deposition Modelling using response surface methodology* justified by Mr. Ashutosh Chouksey in partial fulfilment of the requirements for the degree of Bachelor of Technology in Mechanical Engineering at National Institute of Technology, Rourkela.This is an authentic work carried out by him under my supervision .

To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for award of any degree or diploma.

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CONTENTS

S.NO.	TOPIC	PAGE NO.
1	Introduction	7-10
2	Literature Review	12-13
3	Experimental Plan	16-18
4	Methodology	20-24
5	Results	26-40
6	Conclusion	41
7	References	42-43

ABSTRACT

FDM(fused deposition modelling) is a RP(rapid prototyping)technique used to manufacture prototypes on additive manufacturing technology.The material used is ABS(acronitirile butadiene styrene) plastic.The prototypes are made layer by layer addition of semi molten plastic and their joining by diffusion welding.In the present study effect of different parameters on response is studied.RSM(response surface methodology) is used to build a regression model which can represent response in terms of different parameters.

Influence of the process parameters on each factor is essentially studied and regression equation is built for each of strength under study.By using ANOVA analysis significant factors are considered and unsignificant factors are left out.

After getting regression equation an optimized solution is obtained for each strengthby using a suitable mathematical software.

INTRODUCTION

INTRODUCTION

RAPID PROTOTYPING

FDM(fused deposition modelling) Model works on the principle of Rapid Prototyping(RP methodology).Rapid Prototyping is a group technology which is used to quickly fabricate a scale model of part or assembly using computational drawing techniques like CAD/CAM.These 3-D Printing technology enables user to quickly create prototypes of design compared to earlier technology which only created 2 D pictures.It has several uses like:

1. excellent visual aids for communicating ideas with co-workers or customers.
2. prototypes can be used for design testing.
3. Cheap and quick process
4. Used to make tooling and product quality parts.

In rapid prototyping the term rapid is deceptive as many prototypes require many hours and even days for manufacturing prototype .However when compared to actual manufacturing process it is comparatively much faster process. Rapid Prototyping is also known as solid free form fabrication,compuer automated manufacturing or layered manufacturing as it is increasingly being used in non prototyping applications . This technique slices 3d model into a number of 2d layers which are built on top of each other.The 3d part is a laminate composite with vertically stacked layers consisting of a number of material fibres with interstitial voids. The bonding between different layers is done by diffusion welding .Non uniform bonding and irregular temperature distribution results in brittle and anisotropic nature of the specimen.

THE BASIC PROCESS

All rapid prototyping techniques consists of following basic steps:

1.Formulation of CAD model of the design.

2.Convesion of CAD model into STL format.

3.Slice the STL model into a number of thin layers.

4.Construct the model one above the other so that layers are approximation of model.

5.Clean and finish the model.

FORMULATION OF CAD MODEL

First the object is modelled using a CAD software package.Solid modellers like STAD PRO and CATIA are preferred over wire frame modellers like AUTOCAD.CATIA is used for our analysis purpose.

CAD MODEL TO STL FORMAT

Since different CAD softwares use different algorithms for creation of 3d model STL format is used as a standard by all the prototyping applications .It consists of a number of triangle shaped planar structure which when together stacked on one another are used to approximate the model.This format also stores all information about the coordinates and normal vectors of all the planar surfaces.

CREATION OF THIN LAYERS FROM STL FORMAT

In this step build orientation is decided in which layers will be built.Properly orienting the model helps in reducing the build time .Pre –Processing software slices the STL format according to requirement .

CONSTRUCTION OF AN APPROXIMATE MODEL

The fourth step is actual construction of model in which one of the several rapid prototyping techniques is used for building the model.The process uses one of the several techniques for building the model

FINISHING OF MODEL

This is the final post processing step used for fabrication of the prototype.It involves removal of model from the structure and removal of any extra supports. It also involves treatment of the prototype for removal of any irregularities.Following figure shows the various steps involves in rapid prototyping.

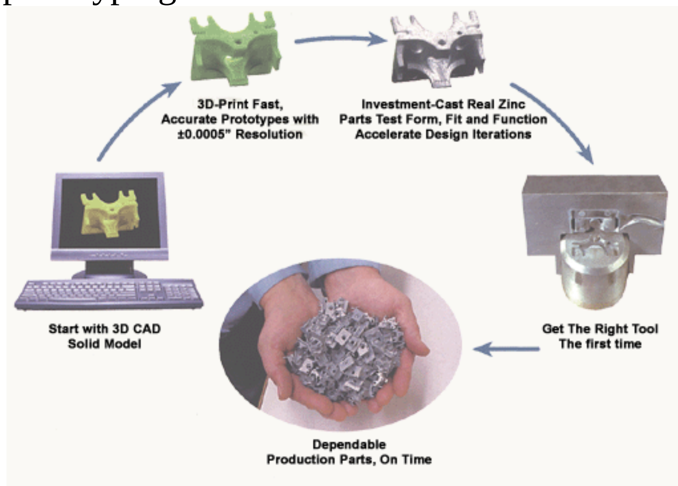


FIGURE 1:FLOW CHART OF RAPID PROTOTYPING

MATERIAL USED FOR FORMATION OF PROTOTYPE

The material used in prototype formation is ABS plastic.ABS (acronitrile butadiene styrene)is a carbon chain copolymer .It is made by dissolving butadiene styrene copolymer in a mixture of acronitrile and styrene monomers.Acronitrile is responsible for providing heat resistance ,butadiene responsible for impact strength and styrene responsible for providing rigidity. Manufacturing of specimen is done by diffusion welding. This results is non uniform distribution of material as welding is non continuous.These non uniformity affect the strength of the specimen and it is therefore necessary to study impact of different process parameters on different types of strength.DOE(design of experiment) helps in reducing the cost and improving the quality of experiment.RSM(response surface methodology)helps in deteming the regression equation which governs different paramaters taken in the experiment.After getting the regression equation an optimized solution is obtained using various optimization techniques like PSO(particle swarm optimization),artificial neural network,genetic algorithm etc.For our purpose we are using genetic algorithm as it is easily comprehensible and understood.

FUSED DEPOSITION MODELLING

Fused deposition modelling is gaining distinct advantage in manufacturing industries because of its ability to manufacture parts with complex shapes without any tooling requirement and human interface. Fused deposition modeling is an additive manufacting technology commonly used for modeling, prototyping, and production applications. FDM works on an "additive" principle by laying down material in layers. A plastic filament is uncoiled from a coil and supplies material to an extrusion nozzle which can be used depending on requirement. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a automated computational mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The model or part is produced by extrusion of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle.A schematic layout of the nozzle and platform arrangement is as shown in figure

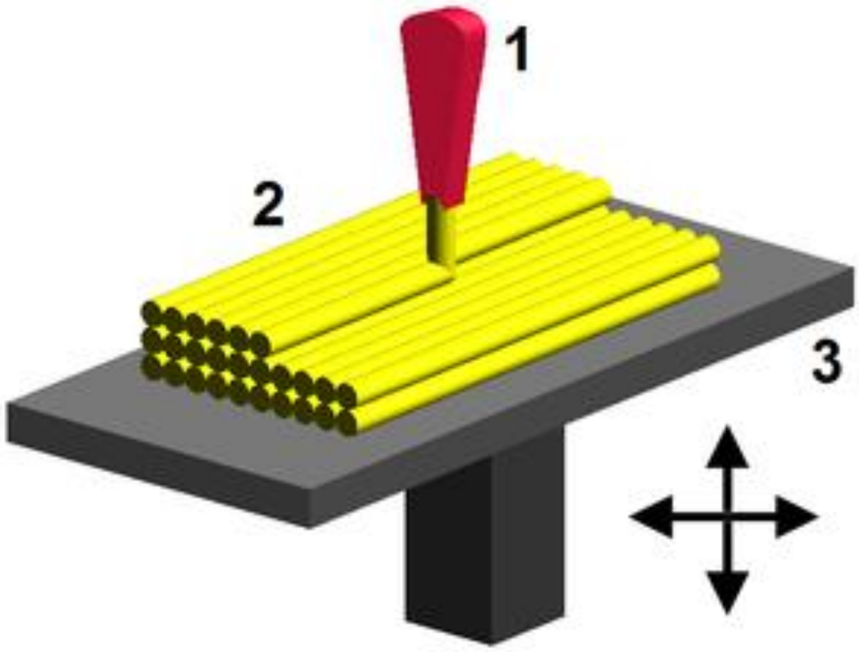


FIGURE 2 :FLOW CHART OF FDM PROCESS

This technology was developed by S.Scott crumo in the 80s.The FDM technology is marketed comerially by Stratasys.Apart from ABS several material are available on which FDM technology can be used .It can be used on polycarbonates.polycaprolactone,polyphenylsulphones and waxes.For providing support during manufacturing a water soluble material is generally used.It is sold by Stratasys under the brand name waterworks.This soluble material is quickly dissolved with metal agitators utilizing a solution of sodium hydroxide as solvent.

Applications:

-conceptual modelling

-Fit,form applications and models for further manufacturing process

-investment casting and injection moulding

Advantages :

-Quick and cheap generation of models

-no worry of exposure to toxic chemicals

Disadvantages:

-limited accuracy due to shape of material used wire is 1.27mm in diameter.

The main benefit rapid prototypoing technologies offer is its ability to manufacture parts of compex geometry without any tooling requirement just by tracing the cad model layer by layer.The ability to manufacture complex parts helps us to substantially reduce production cost ,a concept not possible in traditional manufacturing where complexity in design directly resulted in increased cost due to increased cost of machining.One of the other advantages of RP technologies is their ability to produce functional assemblies by consolidating sub assemblies into one unit thereby reducing the part count ,handling time storage requirement.Inspite of such added advantages it is not possible to implement on a full scale at industrial level because os its limitations in terms of type of product manufactured.To overcome such limitations new materials have to be developed which can be used in RP technologies. Also the parameter controlling the specimen can be optimized to get maximum utilization of properties of existing products. Since mechanical strength is an important parameter governing the properties of material , therefore in our present study we have made an attempt to study different t types of strength like tensile strength ,flexural strength , impact strength and compressive strength .After studying behavor of different types of strength an optimum solution is obtained to get the optimum values of the parameter which govern different types of strength.

LITERATURE REVIEW

LITERATURE REVIEW

Anitha et al[1],by use of taguchi method influence of road width,layer thickness and speed of deposition at three different levels on surface roughness of part produced by the process of FDM is determined.From the results it is indicated that layer thickness is the most influencing factor greatly affecting surface roughness followed by road width and speed of deposition

Sood et al[2],the effect of orientation,layer thickness,raster angle,raster width,raster raster to raster gap is studied with the help of taguchi method on dimensional acuuracy.Significant factors and their interaction are found out using taguchi method.The optimum settings of the parameters are found out so that all the three dimensions show minimum deviation from actual value settings simultaneously and the common factor settings needs to be explored.

Pradhan et al[3],study shows that quality of product considerably influences the properties of the material.Method of response surface methodology is used to analyze the influence of process parameters on surface roughness.By the use of RSM a correlation between process variable and response is established.A second order response model of these parameters is established and deduced that pulse current ,discharge time and interaction term of pulse current with other parameters significantly affect the surface response.

Carley et al[4],various situations are studied in which response surface methodology consists of experimental strategy that can be applied and desired results can be obtained

Lee et al[5],Performed experiments on cylindrical parts using three RP process FDM 3D printer and nano composite deposition(NCDS) to study the effect of build direction on compressive properties.Experimental results show that compressive strength is 11.6% is higher for axial FDM specimen as compared to transverse FDM specimen.In 3D printing diagonal specimen posseses maximum compressive strength in comparison to axial specimen.For,NCDS axial specimen showed compressive strength 23.6% higher than that of transverse specimen.Out of the three RP technologies parts built by NCDS are most affected by build direction.

Khan et al[6],concluded that layer thickness ,raster angle and air gap are found to significantly effect elastic properties of FDM ABS prototype.

Bellehumeur[7],experimentally assessed the bond quality between adjacent fibres and their failure under flexural loading.Experimental results show that both the envelope temperature and variations in convective conditions within the building chamber have strong effect on the meso structure and overall quality of bond strength.On line measurement of cooling temperature profile reveals that temperature profile of the bottom layer rises above the glass away from the position of placement of thermostat and minimum temperature increase with the number of layers.Micrograph of the cross sectional area shows that diffusion of adjacent filaments is more in upper layers as compared to upper layers for the face of specimen with higher number of layers.

Chattoraj et al[8],In this study method of GA is used for optimization of magnetized FMSA.A code of genetic algorithm for magnetized ferro microstrip antenna is developed using C++ and fitness function is obtained.The comparison of the optimized results obtained using GA optimizer of MATLAB is done.

Sood et al[9] In this study five parameters orientation,layer thickness,raster angle.air gap and raster width effect is studied on different mechanical strengths like tensile,flexural,,impact strength is done.Response surface plots for each plot is analyzed and weak strength is attributes to distortion between layers.

EXPERIMENTAL PLAN

EXPERIMENTAL PLAN

FDM machines build prototypes on additive manufacturing technology.It has two nozzles ,one for building of the prototype and other for building of support structure.The experiment is conducted for three parameter based model.Main process parameters used in the experiment are :

1.Layer thickness: It is the thickness of layer deposited by the nozzle and its configuration dependon the shape of prototype and type of nozzle.

2.Orientation:It refers to the inclination of the part in build platform with respect to X,Y,Z axis.The platform is taken as X and Y axis plane and Z axis is taken along build direction.

3.Raster angle:It is the direction of raster build with respect to X axis.

CATIA V5 is used to design the model and it is finally converted to STL(stereolithography) format.STL format is imported to FDM software.CCD(central composite design) is used to design the experimental runs and empirical modelling of the process.In order to model the experiment it is conducted based on CCD.A CCD of second order polynomial is used because it takes into account all the interaction factors.Maximum and minimum value of each factor is coded into -1 and +1 according to the following equation:

$$\varepsilon_{ij} = \frac{x_{ij} - \overline{x}}{\Delta x}$$

Where i=1,2,...K and   j=1,2

Uncoded values for all the codes of the three factors is shown in the table given below.FCCD(face central composite design) is considered for the design of experiment to counteract the effect of machine constraints.

TABLE 1: LEVELS OF PROCESS PARAMETERS

Factors	**Symbols**	**Levels**		
		-1	**0**	**+1**
Layer thickness(mm)	A	0.127	0.178	0.254
Orientation(degree)	B	0	15	30
Raster angle (degree)	C	0	30	60

Analysis of the values obtained on experiment is done on MINITAB R14 software which develops quadratic response design according to following equation

$$y=\beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i x_i + \sum_{i<j} \sum \beta_{ij} x_i x_j$$

Significance of factors is determined by p-value.If regression p-value is less than 0.05 then value is significant and lack of fit p-value more than 0.05 is to be taken.The significance of each term is calculated by a t-test at 95% confidence interval which results in terms having their p-value less than 0.05 rendering them as constant. The coefficient of determination (R^2) indicates the percent of variation in response . It also gives an idea of the fitness of the model.

TABLE 2:Experimental plan based on RSM

Expt no.	A	B	C	Compressive Strength	Flexural Strength	Impact Strength	Tensile Strength
1	**-1**	**-1**	**-1**	**15.210**	**34.2989**	**0.367013**	**15.6659**
2	**1**	**-1**	**-1**	**12.410**	**35.3593**	**0.429862**	**16.1392**
3	**-1**	**1**	**-1**	**10.160**	**18.8296**	**0.363542**	**9.1229**
4	**1**	**1**	**-1**	**10.780**	**24.5193**	**0.426042**	**13.2081**
5	**-1**	**-1**	**1**	**14.280**	**36.5796**	**0.375695**	**16.701**
6	**1**	**-1**	**1**	**15.830**	**38.0993**	**0.462153**	**17.9122**
7	**-1**	**1**	**1**	**7.448**	**39.2423**	**0.395833**	**18.0913**
8	**1**	**1**	**1**	**16.980**	**22.2167**	**0.466667**	**14.0295**
9	**-1**	**0**	**0**	**12.490**	**27.7241**	**0.397222**	**13.4096**
10	**1**	**0**	**0**	**12.340**	**33.0710**	**0.447570**	**15.8933**
11	**0**	**-1**	**0**	**14.980**	**34.7748**	**0.402082**	**14.4153**
12	**0**	**1**	**0**	**12.280**	**25.2774**	**0.388539**	**9.9505**
13	**0**	**0**	**-1**	**11.950**	**27.5715**	**0.382986**	**13.7283**
14	**0**	**0**	**1**	**11.870**	**30.0818**	**0.401388**	**14.7244**
15	**0**	**0**	**0**	**12.880**	**31.9426**	**0.410686**	**13.2189**
16	**0**	**0**	**0**	**11.010**	**29.1475**	**0.401156**	**13.5914**
17	**0**	**0**	**0**	**11.310**	**31.0388**	**0.397712**	**13.8727**
18	**0**	**0**	**0**	**12.670**	**30.1584**	**0.406558**	**13.846**
19	**0**	**0**	**0**	**12.480**	**31.6717**	**0.396373**	**13.063**
20	**0**	**0**	**0**	**11.720**	**29.7678**	**0.407292**	**14.4088**

METHODOLOGY

RESPONSE SURFACE METHODOLOGY

RSM is a regression technique used for determination,prediction and optimization of machine performances.The present study focuses on ABS plastic whose strength is predicted and an optimized solution for the strength of the material is obtained.Response surface methodology is collection of statistical and mathematical technique used for developing ,improving and optimizing process.RSM is used in situations where output is dependent on many parameters.The multi parameter dependent output is called response.RSM involves planning of strategy for development of a relationship between different parameters and output.The relationship between different process parameters and response is approximately represented by the following equation.

$$Y = f\left(\varepsilon_{1,}\varepsilon_{2\ldots\ldots\ldots}\varepsilon_{k}\right) + \epsilon$$

Where Y is the response $\varepsilon_1, \varepsilon_2, \varepsilon_k$are various process parameters,

and the additional term represents the error in measurement of response,background noise etc which together represents the statistical error.Then,

$$E(y) = E\left[f\left(\varepsilon_{1,}\varepsilon_{2\ldots\ldots\ldots}\varepsilon_{k}\right)\right] + E(\epsilon) = f(\varepsilon_{1,}\varepsilon_{2\ldots\ldots\ldots}\varepsilon_{k})$$

Process variables are also called natural variables because it indicates term in natural units such as newton,joule etc.In RSM present work is done by converting the uncoded values to coded variables having low,0 and high levels.In terms of coded variables response surface equation can be approximated as follows

$$\eta\text{=f}(x_1 x_2 \ldots\ldots\ldots..x_k)$$

Where x1,x2... are coded values.In order to approximate the value generally a low order polynomial with very small region of independent variable space is used.The first order model is used when approximation of response surfadce is done on a relatively small region of the independent variable space when there is little curvature in the response surface.

The first order model for two independent variables having coded values is given by following equation.

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2$$

If the interaction between terms is considered then following equation is obtained:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2$$

Addition of interaction terms introduces curvature in the model which is not adequate to give exact approximation of the model.In such cases second order model is used which is depicted by the following equation:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1 x_1 + \beta_{22} x_2 x_2 + \beta_{12} x_1 x_2$$

This model is an exact representation of the model response surface in relatively small surface.The parameters in second order equation is determined by method of least square.

The first order model is represented by the following equation:

$$\eta = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots \ldots . + \beta_k x_k$$

And second order model is represented by the following equation:

$$\eta = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j x_j + \sum_{i<} \sum \beta_{ij} x_i x_j$$

GENETIC ALGORITHM

It is an iteriative optimization technique which works number of a solution in every iteriation rather than one solution.Each string created in the population is a population and is assigned a fitness value . The fitness value for maximization problem is calculated by maximizing -f(x).The string is in the form of a binary digits and goes through following operation in every generation.

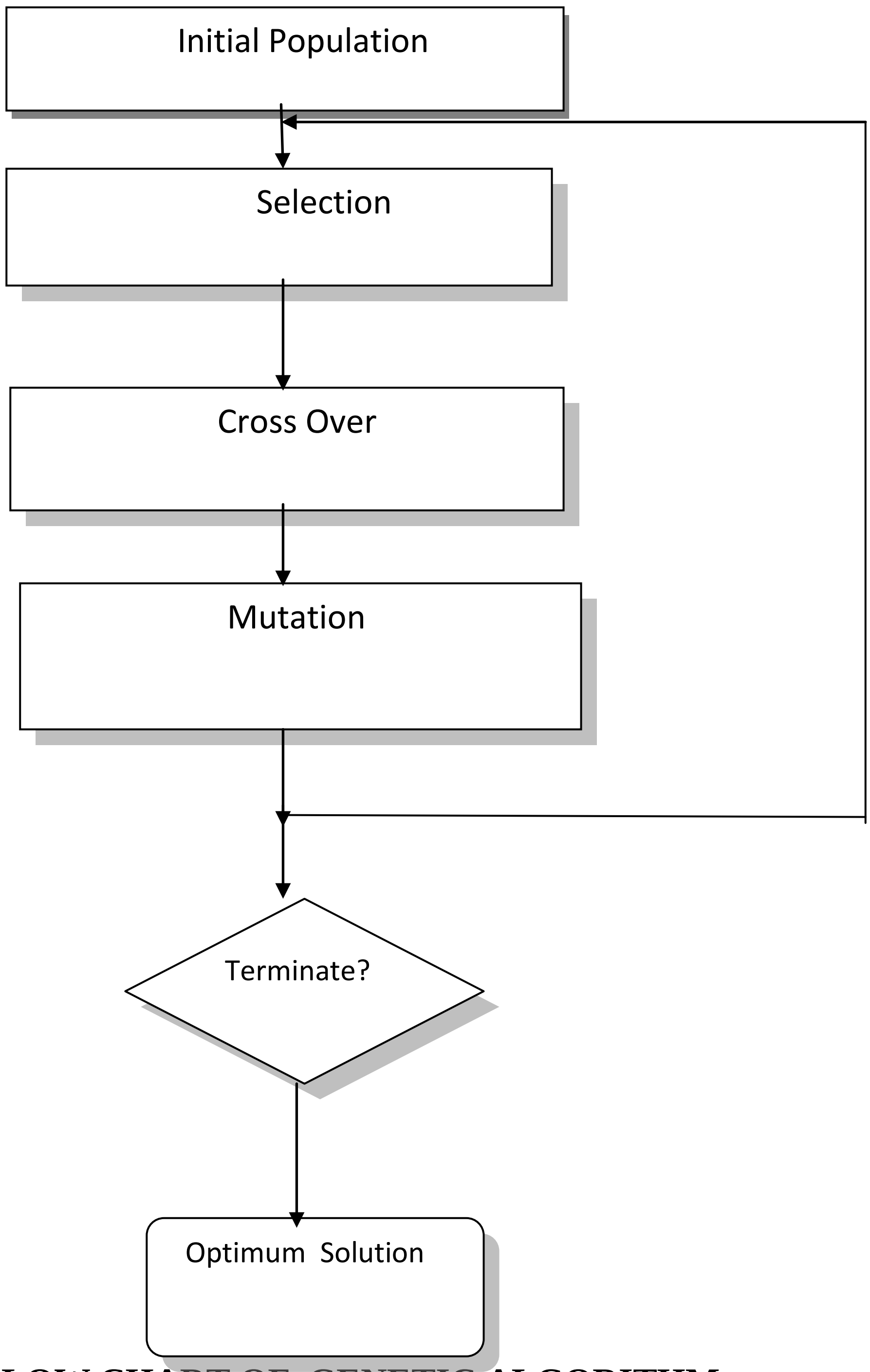
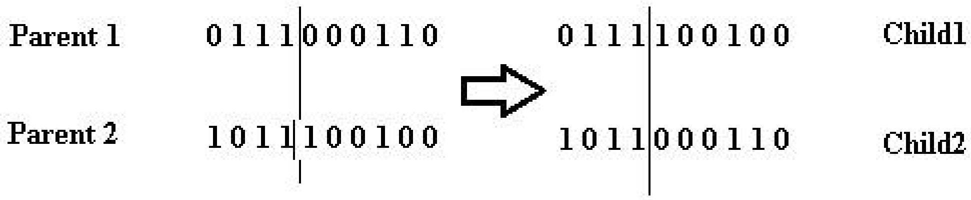


FIGURE 3:FLOW CHART OF GENETIC ALGORITHM

Every iteriation consists of following steps:

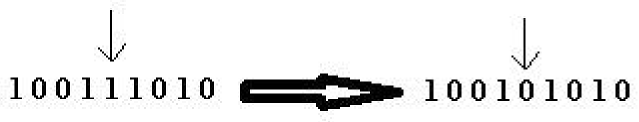
1.Reproduction:It is a procedure of selecting good parents from initial population with best fitness value to produce offspring for the next generation.Population is selected by different selection procedures like proportionate selection method,ranking selection method and tournament selection method.In proportionate selection parents are selected having probability proportional to their fitness values.In ranking selection method parents are selected by arranging strings in ascending order of their fitness values and then selecting parents with best fitness value.In tournament selection two populations are randomly selected and then their fitness values are compared.

2.Crossover: This operation works by selecting random mating points.The following diagram shows schematic representation of the model.



In this operation two strings under consideration are cut at arbitrary positions and portion to the right of the strings are crossed to forms new strings known as child.The fitness value has to reach a certain desired value for the crossover population to stop.The new generation formed after crossover has characteristics similar to that of parents as the genes order may have changed but they come from parent population.

3.Mutation: In this operation any random bit is selected from child string and is changed to the alternate bit .It is schematically represented as follows



As soon as the mutation is over fitness is evaluated and new generation with better finess replace parents with poor fitness values.It brings diversity in the population which would otherwise result in inbreeding.The genetic algorithm is stopped after population is reached certain desired fitness value.

RESULTS AND DISCUSSIONS

RESULTS AND DISCUSSIONS

Analysis of experimental data obtained from FCCD design is done on minitab r14 software.The model used is a full quadratic response model and is represented by the following equation

$$y=\beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i x_i + \sum_{i<j} \sum \beta_{ij} x_i x_j$$

Where xi is the ith factor and Y is the response.

Significance of the values is calculated from F-values of ANOVA table.The significance of any term is established if p-value is less than 0.05 for regression coefficients and more than 0.05 for lack of fit values.An insignificant lack of fit is desirable because it indicates that any term left out of the model is not important and model fits well.

RESPONSE SURFACE REGRESSION:TENSILE STRENGTH

The analysis was done using coded units

TABLE 3:ESTIMATED REGRESSION COEFFICIENTS FOR TENSILE STRENGTH

Term Const	Coef	SE Coef.	T	P
Constant	13.4657	0.4391	30.65	0.000
A	0.4192	0.4039	1.038	0.324
B	-1.6431	0.4039	-4.068	0.002
C	1.3592	0.4039	3.365	0.007
AA	1.4874	0.7703	1.931	0.082
BB	-0.9811	0.7703	-1.274	0.232
CC	1.0613	0.7703	1.378	0.198
AB	-0.2076	0.4516	-0.460	0.656
AC	-0.9261	0.4516	-2.051	0.067
BC	0.8727	0.4516	1.932	0.082

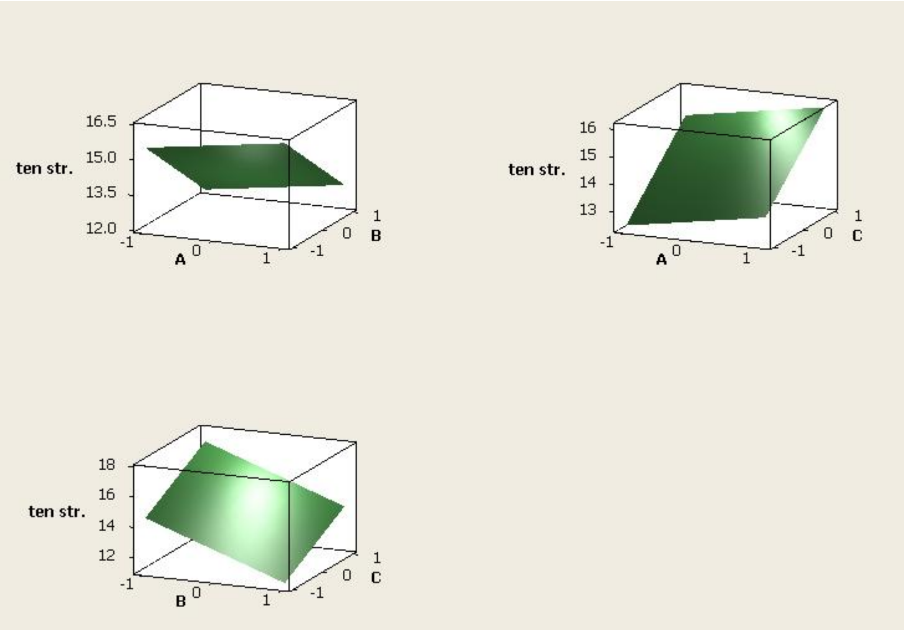
Regression equation for tensile strength

T=13.4657+0.4192*A -1.6431*B +1.3592*C+1.4874*A*A-0.9811*B*B+1.0613*C*C-0.2076*A*B-0.9261*A*C+0.8727*B*C.

TABLE 4: ANALYSIS OF VARIANCE FOR TENSILE STRENGTH

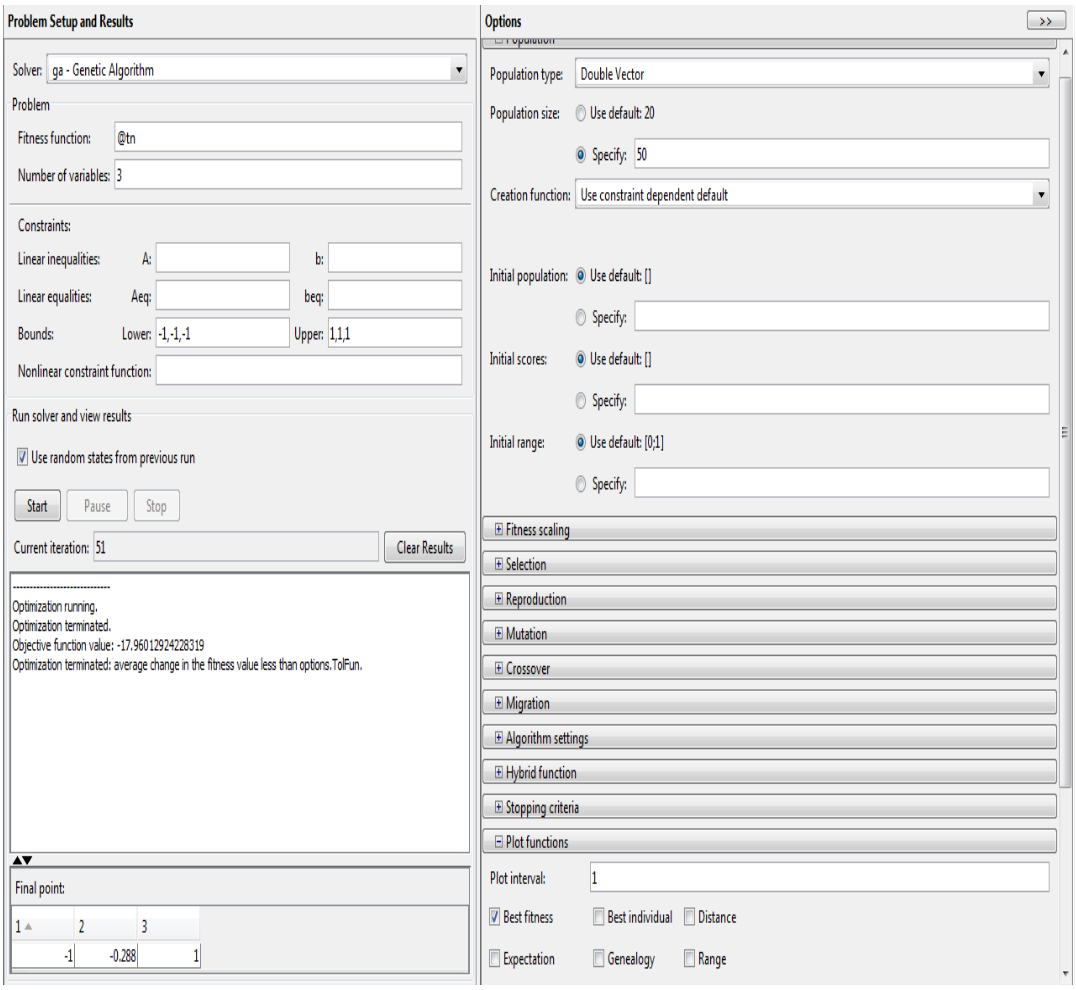
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	76.505	76.505	8.5006	5.21	0.008
Linear	3	47.230	47.230	15.7433	9.65	0.003
Square	3	15.976	15.976	5.3252	3.26	0.068
Interaction	3	13.300	13.300	4.4333	2.72	0.101
Residual Error	10	16.316	16.316	1.6316		
Lack of Fit	5	15.120	15.120	3.0241	12.64	0.007
Pure Error	5	1.196	1.196	0.2392		
Total	19	92.822				

FIGURE 4:SURFACE PLOTS FOR TENSILE STRENGTH



The above results show that tensile strength increaseswith layer thickness and raster angle increasing wheras increase in value of orientation value of tensile strength decreases.For layer thickness reason may be better heat conduction with increased thickness.For orientation non uniform overlapping is the reason for decresing values.

FIGURE 5:OPTIMIZATION OF TENSILE STRENGTH USIN GENETIC ALGORITHM



Optimized value of tensile strength is 17.9601 MPa

Optimized factors in coded form are

A=-1,B=-0.288,C=1,

Optimized values in uncoded form are

A=0.127mm,B= 10.68 deg,C=60 deg

FIGURE 6:CONGRUENCE CURVE PLOT FOR TENSILE STRENGTH

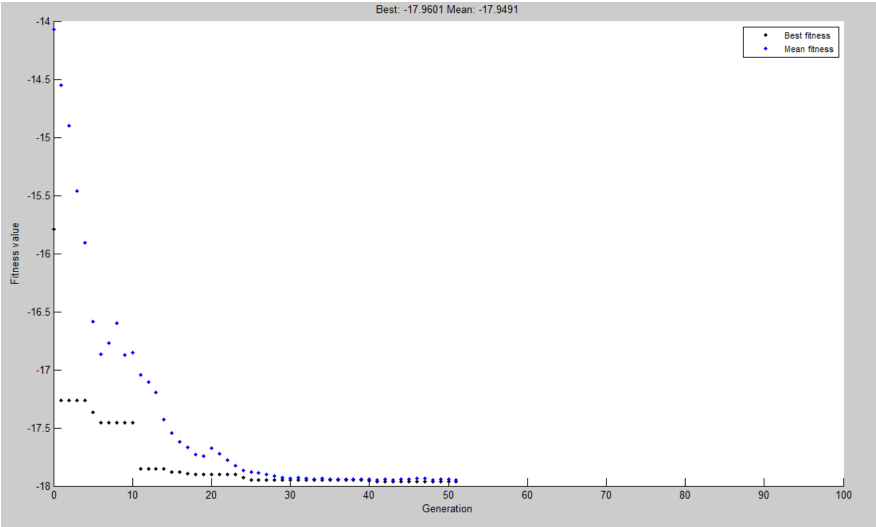
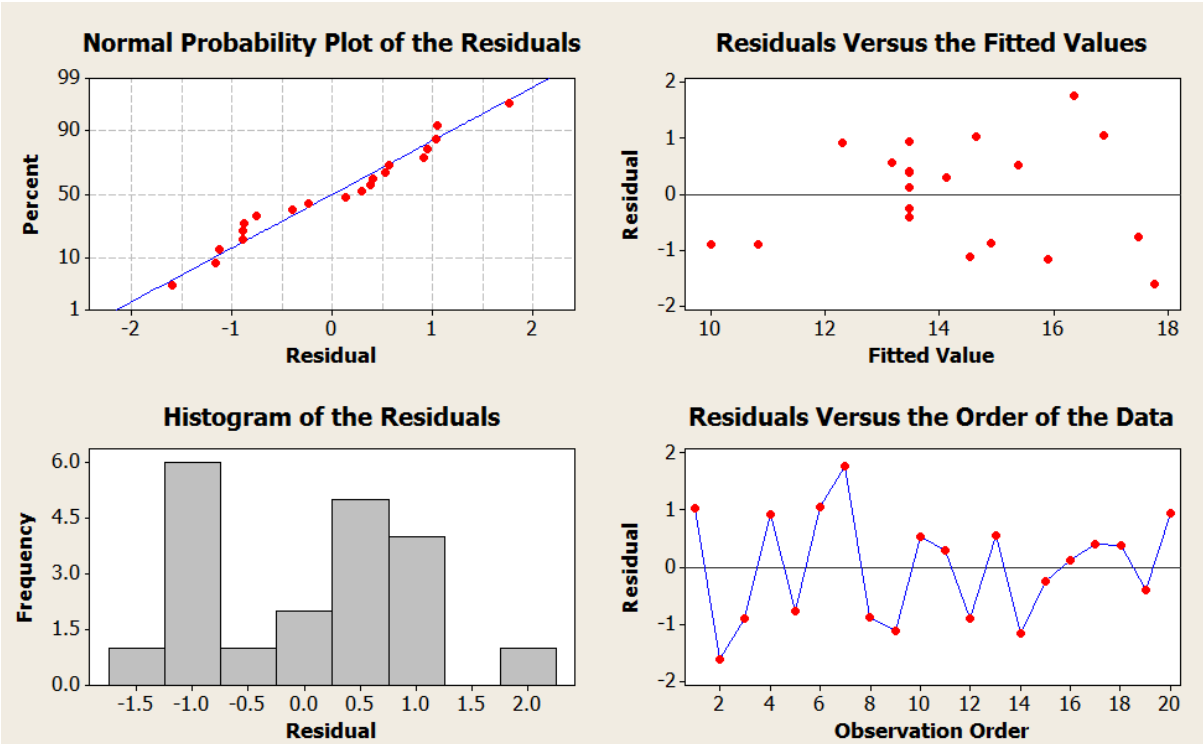


FIGURE 7:RESIDUAL PLOT FOR TENSILE STRENGTH



Since many values have non zero residual it indicates ANOVA analysis has not given proper regression coefficients.Normal probability plot of residue at 95% confidence interval is obtained according to requirement.

RESPONSE SURFACE REGRESSION:IMPACT STRENGTH

The analysis was done using coded units

TABLE 5: ESTIMATED REGRESSION COEFFICIENTS FOR IMPACT STRENGTH

Term Const.	Coef	SE Coef	T	P
Constant	0.402198	0.002555	157.402	0.000
A	0.033299	0.002350	14.167	0.000
B	0.000382	0.002350	0.162	0.874
C	0.013229	0.002350	5.628	0.000
AA	0.021845	0.004482	4.874	0.001
BB	-0.005240	0.004482	-1.169	0.269
CC	-0.008364	0.004482	-1.866	0.092
AB	-0.001997	0.002628	-0.760	0.465
AC	0.003993	0.002628	1.519	0.160
BC	0.003993	0.002628	1.519	0.160

S=0.007433 R-Sq=96.3% R-Sq(adj)=93.0%

In the analysis terms B*B,C*C,A*B,A*C,B*C are insignificant because their p-value is less than 0.05.The coefficient of determination is 91.6% which indicates good fitness of the model.

TABLE 6:REGRESSION COEFFICIENTS USING SIGNIFICANT UNITS

Term Const	Coef	SE Coef	T	P
Constant	0.399477	0.0028994	138.032	0.000
A	0.033299	0.002894	11.506	0.000
B	0.000382	0.002894	0.132	0.897
C	0.013229	0.002894	4.571	0.000
AA	0.013683	0.004093	3.343	0.004

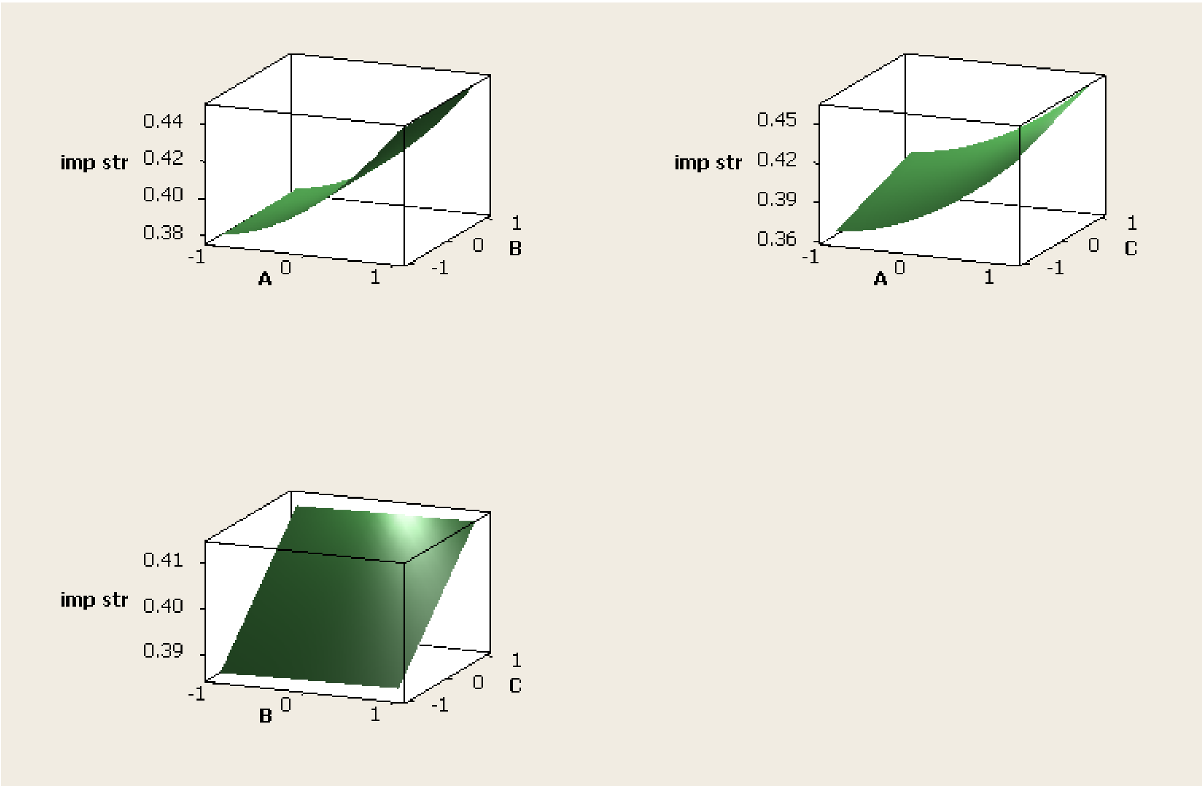
Regression eqution using significant units are

I=0.399477+0.033299*A+0.000382*B+0.013229*C+0.013683*A*A.

TABLE 7: ANALYSIS OF VARIANCE FOR IMPACT STRENGTH

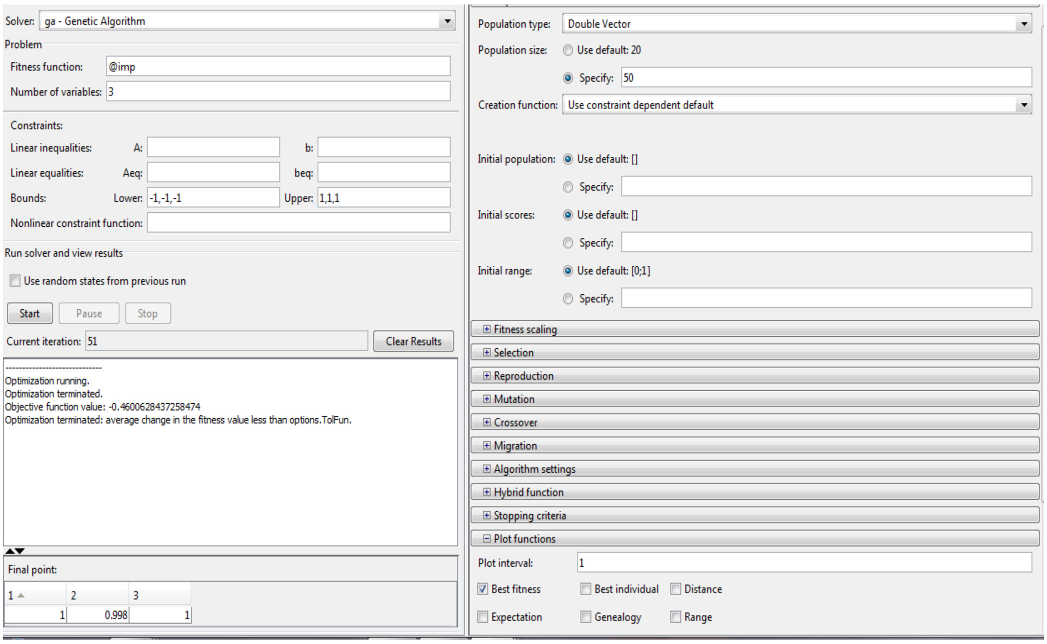
Source	DF	Seq. SS	Adj. SS	Adj MS	F	P
Regression	4	0.013776	0.01376	0.003444	41.12	0.000
Linear	3	0.012840	0.012840	0.004280	51.10	0.000
Square	1	0.000936	0.000936	0.000936	11.18	0.004
Residual Error	15	0.001256	0.001256	0.000084		
Lack of Fit	10	0.001091	0.001091	0.000109	3.31	0.099
Pure Error	5	0.000165	0.000165	0.000033		
Total	19	0.015032				

FIGURE 8:SURFACE PLOTS FOR IMPACT STRENGTH



Values of impact strength increases with increase in layer thickness and raster angle whereas remains constant for orientation.Since load is suddenly applied more thickness results in increased strengths .Since air gaps hardly affect impact strength its values remains constant.With increase in raster angle length of individual raster is more resulting in increased strengths at higher values.

FIGURE 9:OPTIMIZATION OF IMPACT STRENGTH USING GENETIC ALGORITHM



Optimized value of impact strength is 0.4600628 MJ/m^2

Optimized factors in coded form are

A=1,B=0.998,C=1.

Optimized factors in uncoded form are

A=0.254mm,B=29.94,C=60 deg

FIGURE 10:RESIDUAL PLOT FOR IMPACT STRENGTH

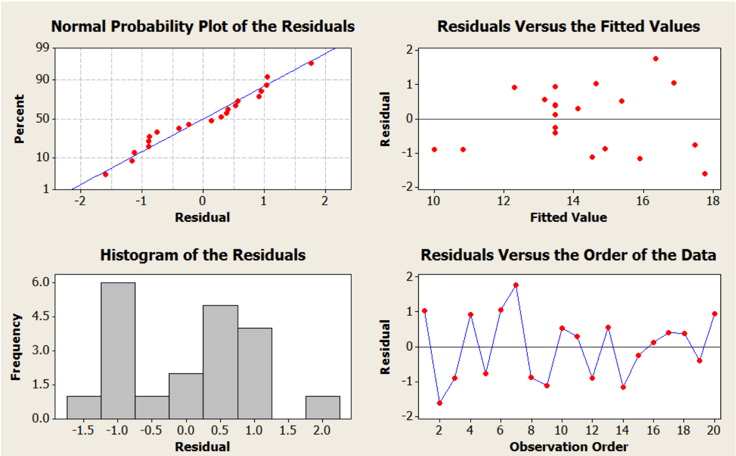
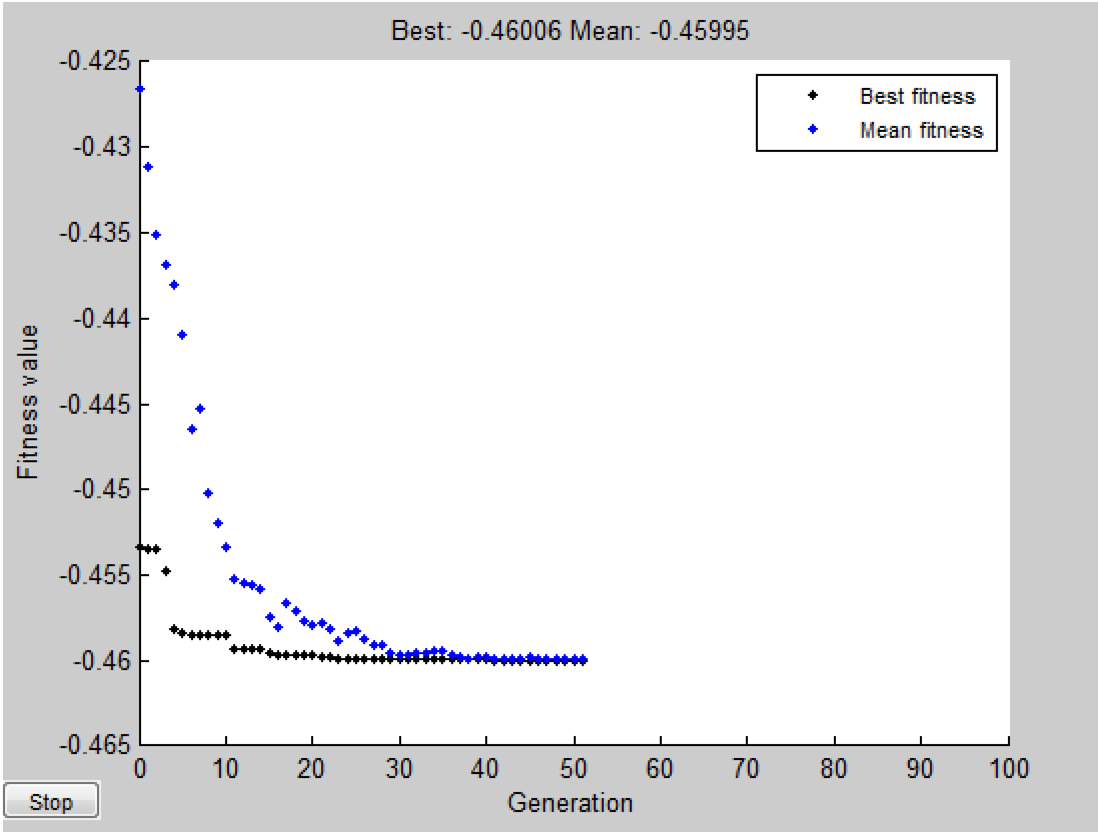


FIGURE 11:CONGRUENCE CURVE PLOT FOR IMPACT STRENGTH



RESPONSE SURFACE REGRESSION : FLEXURAL STRENGTH

The analysis was done using coded units

TABLE 8: ESTIMATED REGRESSION COEFFICIENTS FOR FLEXURAL STRENGTH

Term Const.	Coef.	SE Coef	T	P
Constant	30.1651	1.112	27.129	0.000
A	-0.3409	1.023	-0.333	0.746
B	-4.9027	1.023	-4.793	0.001
C	2.5641	1.023	2.507	0.031
AA	0.9164	1.950	0.470	0.649
BB	0.5450	1.950	0.279	0.786
CC	-0.6545	1.950	-0.336	0.744
AB	-1.7395	1.144	-1.521	0.159
AC	-2.7820	1.144	-2.433	0.035
BC	1.6362	1.144	1.431	

S=3.234 R-Sq=80.1% R-Sq(adj)=62.1%

In the above analysis terms A,B,C,A*A are significant as their p-value is less than 0.05.The coefficient of determination is 80.1%

TABLE 9:REGRESSION COEFFICIENTS USING SIGNIFICANT UNITS

Term Const.	Coef	SE Coef.	T	P
Constant	30.5686	0.7196	42.483	0.000
A	-0.3409	1.0176	-0.335	0.742
B	-4.9027	1.0176	-4.818	0.000
C	2.5641	1.0176	2.520	0.024
AC	-2.7820	1.1377	-2.445	0.027

S=3.218 R-Sq=70.4% R-Sq(adj)=62.5%

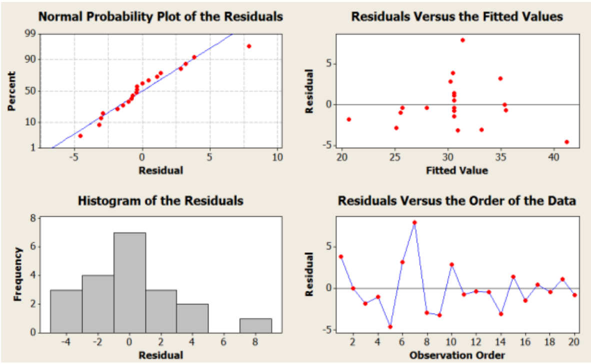
Regression equation for flexural strength

F=30.5686-0.3409*A-4.9027*B+2.5641*C-2.7820*A*C;

TABLE 10: ANALYSIS OF VARIANCE FOR FLEXURAL STRENGTH

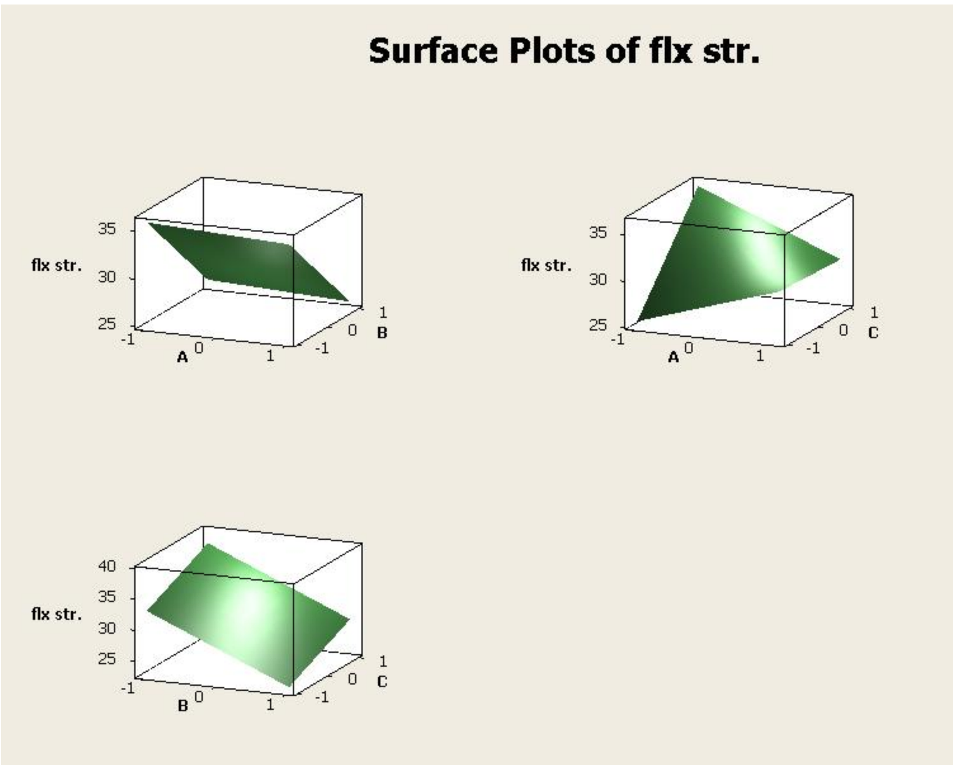
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	4	369.186	369.186	92.296	8.91	0.001
Linear	3	307.269	307.269	102.423	9.89	0.001
Interaction	1	61.916	61.916	61.916	5.98	0.027
Residual Error	15	155.326	155.326	10.355		
Lack of Fit	10	149.188	149.188	14.919	12.15	0.006
Pure Error	5	6.138	6.138	1.228		
Total	19	524.512				

FIGURE 12:RESIDUAL PLOTS FOR FLEXURAL STRENGTH



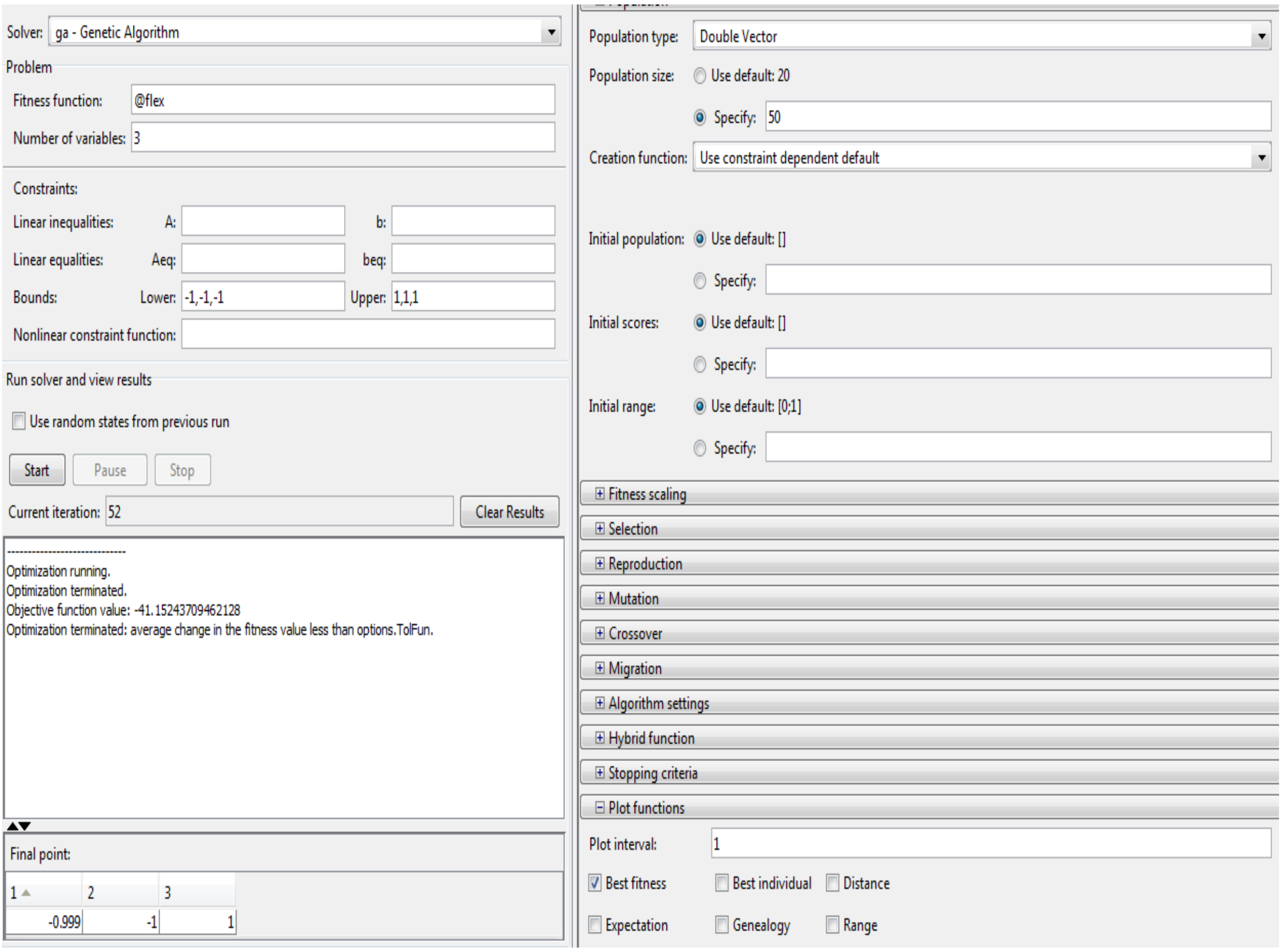
Probability plot at 95% C.I is obtained as desired .A bell shaped frequency residual plot is obtained indicating ANOVA analysis is as desired and for most of the values residue is zero.

FIGURE 13:SURFACE PLOTS FOR FLEXURAL STRENGTH



Values of layer thickness and raster angle is direcly proportional to tensile strength whereas it is inversely proportional to values of orientation.For layer thickness higher values give more resistance to the applied loads .Non uniform overlaaping may lead to weakening of specimen hence decreases with orientation.At lower raster angles length of the individual raster is more and inclination along the length of the specimen is also more resulting in increased strength with increase in values of raster angle.

FIGURE 14:OPTIMIZATION OF FLEXURAL STRENGTH USING GENETIC ALGORITHM



Optimized value of flexural strength is 41.152 MPa

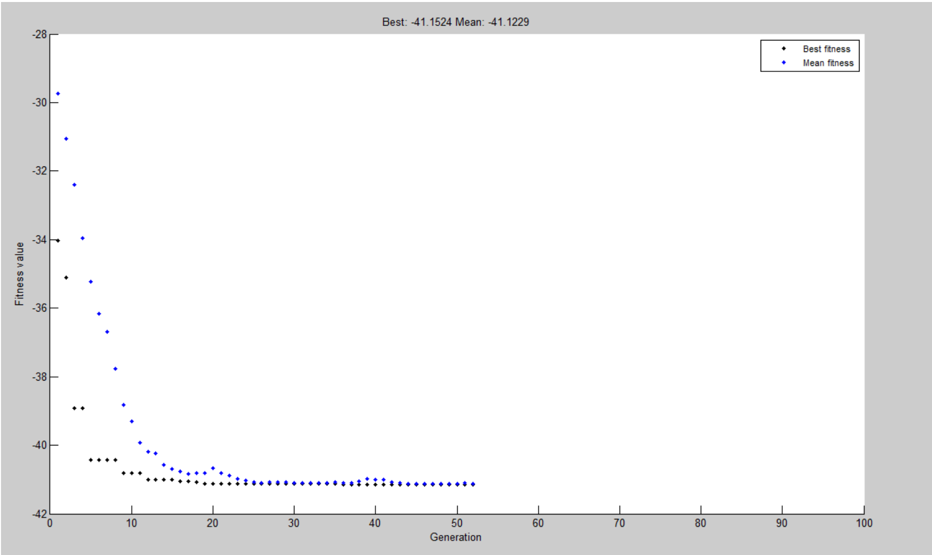
Optimized value of coded factors are

A=-0.999,B=-1,C=1

Optimized value of uncoded factors are

A=0.126873 mm,B=0 deg,C=60 deg

FIGURE 15:CONGRUENCE CURVE PLOT FOR FLEXURAL STRENGTH



RESPONSE SURFACE REGRESSION : COMPRESSIVE STRENGTH

The analysis was done using coded units

TABLE 11:ESTIMATED REGRESSION COEFFICIENTS FOR COMPRESSIVE STRENGTH

Term Const.	Coef.	SE Coef.	T	P
Constant	12.1636	0.3329	36.543	0.000
A	0.8752	0.3062	2.858	0.017
B	-1.5062	0.3062	-4.919	0.001
C	0.5898	0.3062	1.926	0.083
AA	0.0235	0.5839	0.040	0.969
BB	1.2385	0.5839	2.121	0.060
CC	-0.4815	0.5839	-0.825	0.429
AB	1.4253	0.3423	4.163	0.002
AC	1.6578	0.3423	4.843	0.001
BC	0.1248	0.3423	0.364	0.723

S=0.9682 R-Sq=89.2% R-Sq(adj)=79.5%

In the above analysis terms A,B,C,A*B,A*C are significant.The coefficient of determination is 82.9%.

Regression equation for the above analysis is

C=12.5539+0.8752*A-1.5062*B+0.5898*C+1.4253*A*B+1.6578*A*C.

TABLE 12:REGRESSION COEFFICIENTS USING SIGNIFICANT UNITS

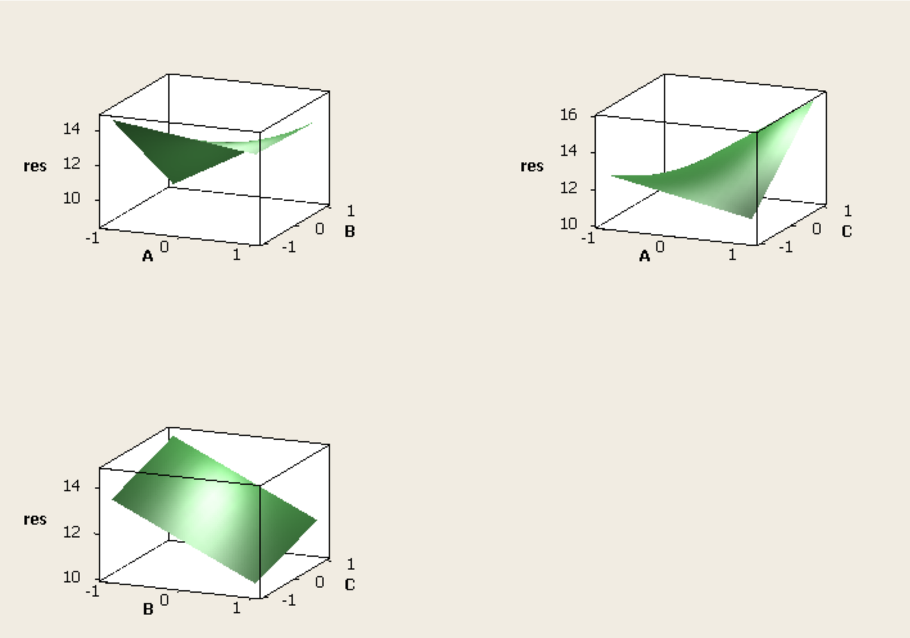
Term	Coef	SE Coef	T	P
Constant	12.5539	0.2304	54.494	0.000
A	0.8752	0.3258	2.686	0.018
B	-1.5062	0.3258	-4.623	0.000
C	0.5898	0.3258	1.810	0.092
AB	1.4253	0.3643	3.913	0.002
AC	1.6578	0.3643	4.551	0.000

S=1.030 R-Sq=82.9% R-Sq(adj)=76.8%

TABLE 13: ANALYSIS OF VARIANCE FOR COMPRESSIVE STRENGTH

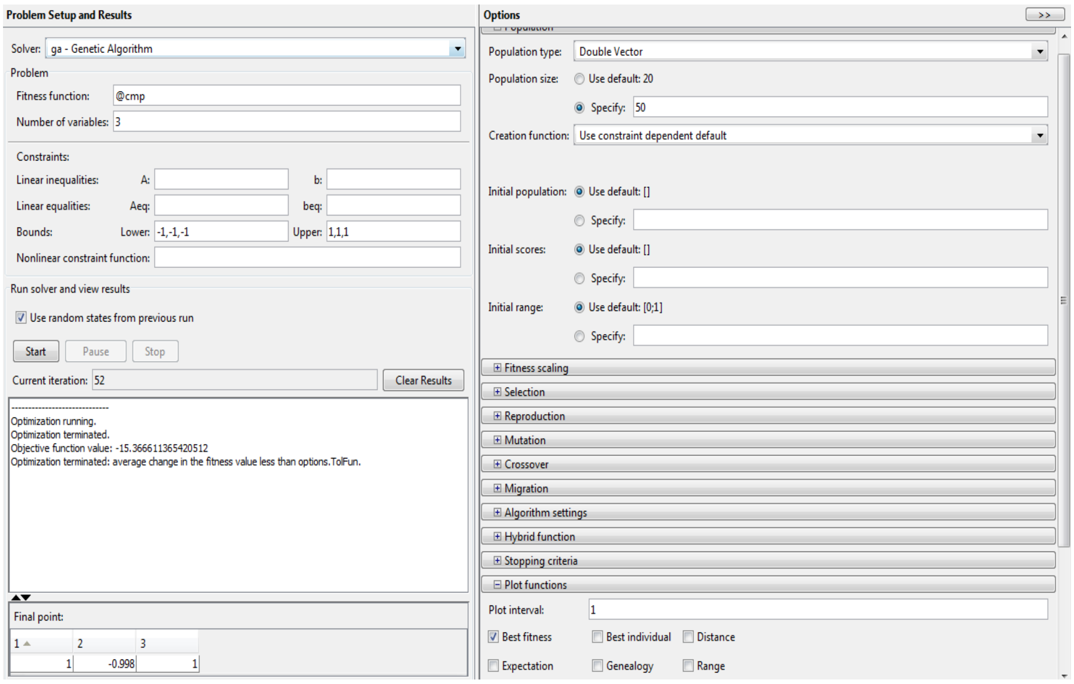
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	72.061	72.061	14.4121	13.58	0.000
Linear	3	33.825	33.825	11.2749	10.62	0.001
Interaction	2	38.236	38.236	19.1179	18.01	0.000
Residual Error	14	14.860	14.860	1.0614		
Lack of Fit	9	11.873	11.873	1.3192	2.21	0.198
Pure Error	5	2.987	2.987	0.5975		
Total	19	86.921				

FIGURE 16:SURFACE PLOTS FOR COMPRESSIVE STRENGTH



Values of compressive strength first increases and then decreases with increasing values of layer thickness.Compressive strength first decreases with increasing orientation and increases with raster angle .Reasoning can be similarly done as in previous cases.

FIGURE 17:OPTIMIZATION OF COMPRESSIVE STRENGTH USING GENETIC ALGORITHM



Optimized value of compressive strength is 15.3661 MPa

Optimized value of coded factors are

A=1,B=-0.998,C=1

Optimized value of uncoded factors are

A=0.254mm,B=0.03,C=60 deg

FIGURE 18:CONGRUENCE CURVE PLOT FOR COMPRESSIVE STRENGTH

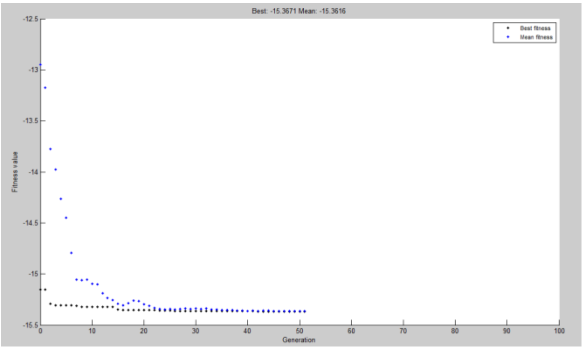


FIGURE 19:RESIDUAL PLOTS FOR COMPRESSIVE STRENGTH

A bell shaped curve is obtained for frequency residue plot indicating less variation from actual values.Probability plot is obtained as per requirement.

CONCLUSION

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Effect of three process parameters i.e. layer thickness , orientation, raster angle is studied on four types of responses i.e. tensile strength, impact strength, flexural strength, compressive strength . Design of experiment for doing the experiments makes use of face central composite design (FCCD).Empirical relationship between response and different process parameters is established and its validity is checked using ANOVA analysis. Residual surface plots are obtained using MINITAB R14 and it shows variability between actual response and predicted response. Response surface plots are also obtained between different parameters which gives an idea of behaviour of output on varying two parameters simultaneously. It shows that output at any point depends on value of different process parameters at that point. The weak strength of the processed parts can be attributed to weak bonding between different layers.

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