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Optimization of impact behavior of bio particulated coir-vinyl ester composites using simulated annealing with post analysis

R Ramprasath[1, a] & S Jayabal[2]

[1]Sri Aravindar Engineering College, Sedarapet 605 111, India

[2]A C College of Engineering and Technology, Karaikudi 630 003, India

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The present investigation is focused on evaluation and optimization of impact behavior of bio particulated coir-vinyl ester composites. The bio particles such as groundnut shell, alumina and termite mound soil have been selected and their influences on the impact behavior of coir -vinyl ester composites are evaluated. The bio particulated composite fabrications are planned as per full factorial design with the different levels of fibre length, fibre content and particulate content. The impact strength of fabricated composites is evaluated. The nonlinear regression models are developed for the prediction of impact behaviors over the specified range of conditions. The fabrication parameters for the maximum value of impact behaviors are also determined using simulated annealing algorithm and conformance checking is carried out using post analysis. The optimum values of impact behaviors of 39.5, 45.9 and 52.1 kJ/m^2 are obtained in coir-vinyl ester composites reinforced with groundnut shell, alumina and termite mound soil respectively.

Keywords: Bio particulates, Coir - vinyl ester composites, Impact strength, Simulated annealing

1 Introduction

The fibre reinforced polymer composites are used in recent years because of their inherent properties including light weight, low density, low cost and specific strength[1]. Natural fibre based polymer composites, depending on fibre specific characteristics, could also find a position within the wide scale of applications and products in engineering field[2]. The use of fillers offers a number of advantages such as improved stiffness, dimensional stability and better thermal properties compared to that of neat, unmodified polymer. The usage of industrial wastes and bio particulates in polymer composite applications was started in recent years. Some of the researchers effectively used red mud as fillers in polymer composite applications[3]. The effect of calcium carbonate on the mechanical behaviors of coir-polyester composites are studied recently[4,5]. The alumina particles and their contribution for the improvement of mechanical strength of coir-polyester composites are listed in literatures[6]. The microstructure of termite mound soil are studied in recent years[7, 8]. The previous attempts by various researchers to incorporate bio particulates in polymer composites initiated a new platform for the development of bio particulate-coir-vinyl ester composites. Taking this into consideration, in this study groundnut shell, alumina and termite mound soil bio particulates were introduced in coir fibre reinforced vinyl ester composites. The non linear mathematical models were developed for predicting the impact strength behaviors of the composites using regression analysis and the developed models were optimized using simulated annealing with post analysis.

[a] Corresponding author.
E-mail: ramsince1979@yahoo.com

2 Materials and Methods

2.1 Coir Fibre

The green husk coir fibre (average fibre diameter 0.10-0.25 mm, fibre length up to 150 mm, density 1.40 g/cc, water absorption 40 % and moisture regain at 65 % RH 10.5 %) was selected as reinforcement material in this study. The cross - section area of the fibre subjected to single filament test was determined using Rapid I machine vision system. The tensile test procedure ASTM D 2256 was used to conduct single filament test for coir fibres. The monofilament of each fibres was tested using the Instron testing machine (Model 5500 R) at the loading rate of 5 mm/min until the fibre fractures at 21 ± 1 ^{0}C and at of 55 ± 2 % RH. To obtain a statistically significant result, 20 fibres were tested to evaluate the average tensile strength properties (mean breaking strength 4.9 N, average tensile strength 521 MPa, fracture strain 1.65%, young's modulus 14.16 GPa and specific stress 372.14 MPa.cm^3/g).

2.2 Vinyl Ester Resin

Vinyl ester has been selected as matrix material for this investigation because it combines the best properties of epoxy and unsaturated polyesters resin. This can be easily handled at room temperature and have mechanical properties better than polyester and similar to epoxy resins. Vinyl ester has better chemical resistance, hydrolytic stability, and at the same time offers superior control over rate of curing and reaction conditions. The properties of vinyl ester resin are given below.

Specific gravity@25^{0}C	:	1.0 to 1.1
Viscosity @ 25^{0}C	:	1.5 poise
Gel time	:	22 - 30 min
Heat Distortion Temperature	:	372 K
Styrene content	:	33 %

2.3 Bio Particulates

Groundnut botanically known as *Arachis hypogeae* belongs to Leguminosae family. It is the fourth largest oilseed produced in world, and India is the second largest producer of groundnut after China. Aluminum oxide is an inorganic material that has the potential to be used as filler in various polymer matrices. Aluminum oxide (Al_2O_3) commonly referred to as alumina can exist in several crystalline phases all of which revert to the most stable hexagonal alpha phase at elevated temperatures. It is hard, wear-resistant, and poses excellent dielectric properties, resistance to strong acid and alkali attack at elevated temperatures. The termite mound soil is collected from locally available termite mounds. Termite mound soil is also taken from mound surfaces, mound perimeters (interface of mound and surrounding soil) and surrounding soils which are enriched with 94 % of SiO_2.

2.4 Composite Manufacturing

The matrix system consisting of unsaturated vinyl ester resin, 1.5 % cobalt octoate accelerator, 1.5 % methyl ethyl ketone peroxide (MEKP) catalyst and 1.5% di-methyl aniline promoter was used. The bio particulate was blended with resin system for different percentage of weight content using simple mechanical stirring at 20 rpm for 10 min at 25^{0}C. A mould with the size of 300 × 300 × 3 mm^3 was used for composite fabrication. The fabrication parameters and their levels are given in Table 1.

2.5 Impact Testing

The specimens for impact test were cut from the manufactured composite and finished to the accurate size using emery paper. The Izod impact test was carried out using Tinius Olsen (Model 104) impact tester as per ASTM D 256-10 standard. Five specimens with identical dimensions of 65 mm × 12.5 mm × 3 mm were prepared for composite testing and average result was derived. The specifications of impact tester and testing conditions are given below.

Maximum pendulum capacity	:	25 J
Maximum impact velocity	:	3.46 m/s
Testing conditions	:	Temp. 23±2 °C RH 50 ±5 %

The test specimen was supported as a vertical cantilever beam and broken by a single swing of a pendulum. The pendulum strikes the face of the sample and total of 5 samples were tested ; the mean value of the absorbed energy was taken. Energy absorbed (*U*) by the specimen is calculated using the following formula:

$$U = \frac{W}{2g}\left(u_1^2 - u_2^2\right)$$

where *W* is the weight of striking head; u_1, the velocity of striking head just before impact; u_2, the measured velocity of striking head just after impact; *g*, the acceleration due to gravity; and *H*, the drop height.

2.6 Simulated Annealing Algorithm

The simulated annealing algorithm was used in this study to optimize the impact behavior of bio particles impregnated coir- vinyl ester composites. Simulated annealing algorithm is inspired by annealing in metallurgy which is a technique of controlled cooling

Table 1—Selection of parameters and levels

Levels	Fibre length mm	Particulate content wt %	Fibre content wt %	Resin content wt %
1	10	05	35	60
2	20	10	30	60
3	30	15	25	60
4	40	20	20	60
5	50	25	15	60

of material to reduce defects[9]. The following steps were adopted in simulated annealing[10].

Step 1—Choose an initial point $x^{(0)}$, set a termination criterion €, set temperature T at a sufficiently high value, number of iterations to be performed n and set initial iteration $n = 0$.

Step 2—If X_i denotes the current point, random moves are made along each coordinate direction, in turn. The new coordinate values are uniformly distributed around the corresponding coordinate of X_i. A candidate is accepted or rejected according to a criterion, known as the metropolis criterion.

Step 3—If function differences $\Delta f = f(x_{(n+1)}) - f(x_{(n)}) < 0$, set $n = n+1$, otherwise, accept the new point with a probability of $P(\Delta f) = \exp(-\Delta f/kT)$, k is a scaling factor called Boltzmann's constant. The value of k influences the convergence characteristics of the method.

Step 4—If $|x_{(n+1)} - x_{(n)}| <$ € and T is small, terminate; Otherwise lower the cooling schedule. Go to step 2.

3 Results and Discussion

3.1 Influence of Particle Impregnation

The groundnut impregnated coir fibre reinforced vinyl ester composites exhibit low impact strength value compared to that of alumina particles impregnated coir fibre reinforced vinyl ester composites. The impact strength of termite mound particles impregnated coir fibre reinforced vinyl ester composites is found to be superior to all other particles considered in this study. The impact strength of the bio particles impregnated coir fibre reinforced vinyl ester composites shows a increasing trend with the increase in fibre length and particulate content but when the fibre length is increased further than 30 mm , the impact strength is found to decrease for all type of particles permeated in coir fibre reinforced vinyl ester composites. The influences of particles impregnation on impact strength are depicted in Fig.1.

3.2 SEM Analysis of Fractured Surfaces

The fracture of coir fibre [Fig. 2(a)] reveals that coir fibre has shredded completely and resists applied load to some extent. The SEM images of fractured specimens after mechanical testing are shown in Figs 2 (b)-(d). The better groundnut particles - matrix adhesion is confirmed with the SEM images as shown in Fig. 2 (b). The SEM image of impact tested specimen [Fig. 2(c)] shows that the distributions of alumina particles enhance the adhesion of fibre with the matrix materials. The random distribution of termite mound soil particles over the matrix surface is observed form Fig. 2 (d). Due to the presence of bio particles, the matrix is strengthened and quick failure of matrix during the test is avoided.

3.3 Nonlinear Regression Analysis

The mathematical models for correlating the impact strength of particulates impregnated coir-vinyl ester composites and fabrication parameters are obtained from the coefficients, resulting from the statistical software. The R^2 values for impact model of groundnut, alumina and termite mound soil particulated coir-vinyl ester composites are 0.925, 0.925 and 0.913 respectively. The impact properties of particulates impregnated coir-vinyl

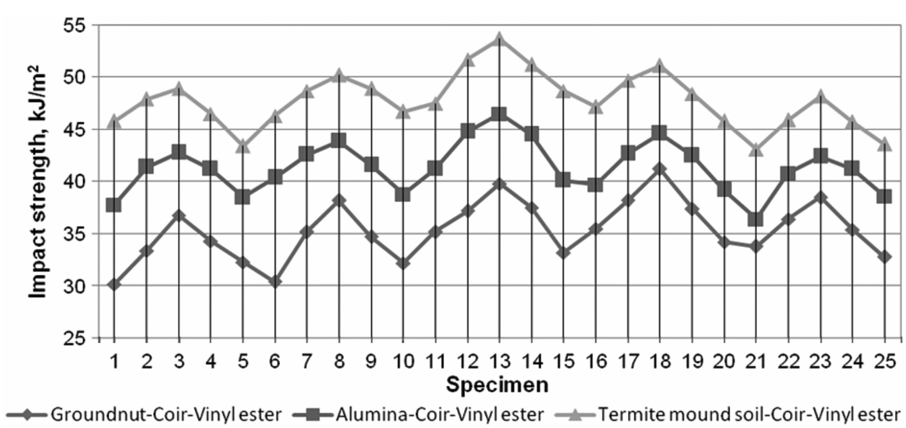

Fig.1—Influence of fabrication parameters on impact strength

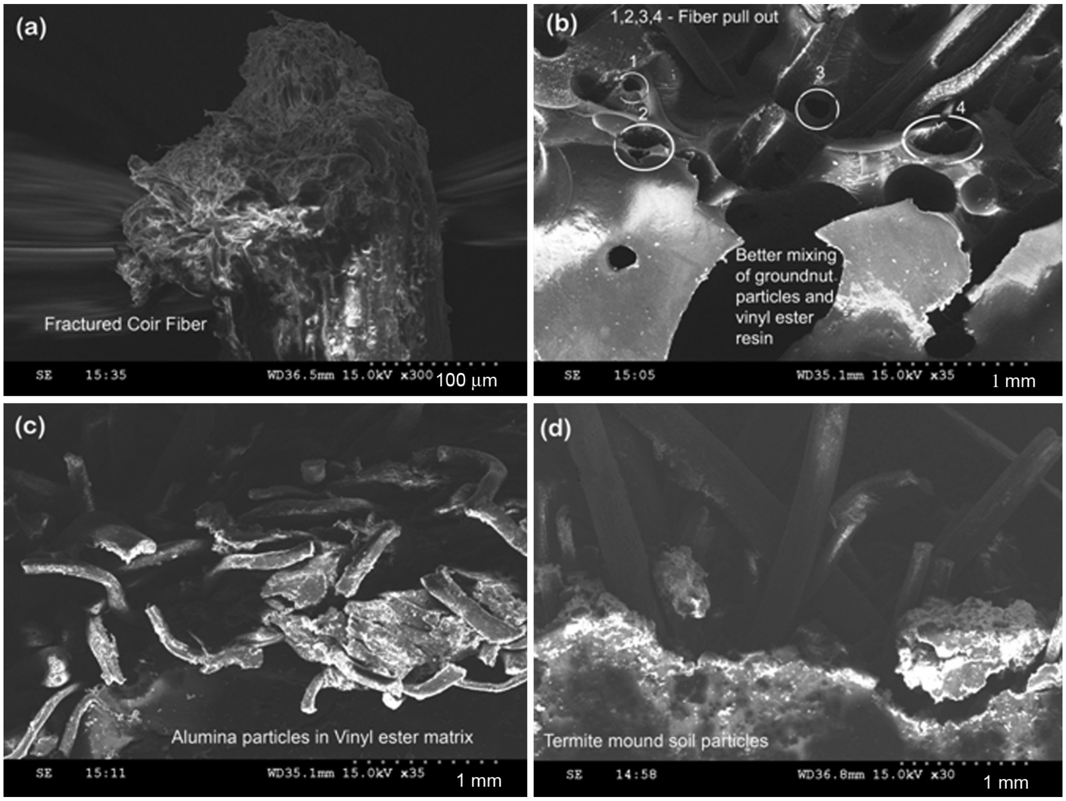

Fig.2—SEM images of fractured (a) coir fibre, (b) ground nut composite, (c) alumina composite and (d) termite mound soil composite

ester composites exhibit cubic nature as shown below:

$$gn = 24.5 + 0.972\,f - 0.987\,p - 0.0129\,fp - 0.0148\,f^2 + 0.126\,p^2 + 0.000176\,fp^2 - 0.000043\,f^2p - 0.000003\,f^3 - 0.00319p^3$$

$$al = 30.7 + 0.677\,f + 0.424\,p + 0.0099\,fp - 0.0150\,f^2 - 0.0070\,p^2 - 0.000114\,fp^2 - 0.000013\,f^2p + 0.000060\,f^3 - 0.000489\,p^3$$

$$tms = 37.1 + 0.718\,f + 0.377\,p + 0.0050\,fp - 0.0165\,f^2 + 0.0130\,p^2 + 0.000006\,fp^2 - 0.000059\,f^2p + 0.000077\,f^3 - 0.00118\,p^3$$

where *gn* is the impact strength in kJ/m^2 (groundnut); *al*, the impact strength in kJ/m^2 (alumina); *tms*, the impact strength in kJ/m^2 (termite mound soil); *f*, the fibre length in mm; and *p*, the particulate content in weight %.

3.4 Interaction Plots

The interaction plots to study the effect of fibre length and particulate content on impact strength in bio particulates impregnated coir-vinyl ester composites are shown in Fig. 3. The figures describe the nonlinear pattern of response distribution. The impact properties are found to be maximum with the fibre length of 30 mm. The maximum values of impact strength are obtained for the particulate content of 15 % and 20 % for the different values of fibre length. Correspondingly, the better value of impact strength is obtained between 20 % and 25 % of fibre content in weight.

3.5 Optimization by Simulated Annealing

The nonlinear regression equations are optimized using simulated annealing procedure by setting starting point and side constrains. The fast annealing function and exponential temperature update are selected in this investigation. The SA algorithm available in GUI of MAT LAB R2010a is used to find out the optimum conditions for maximum value of impact behaviors (Fig. 4). The optimum value of impact strength of 39.5 kJ/m^2 is obtained for the fibre length of 25 mm, particulate content of 20.3 % and fibre content of 19.7 % in groundnut impregnated coir-vinyl ester composites. The alumina impregnated coir-vinyl ester composites exhibit optimum impact strength of 45.9 kJ/m^2 at the fibre length of 33 mm, particulate content of 16.2 % and fibre content of 23.8 %. The optimum value of impact strength obtained by simulated annealing algorithm for termite

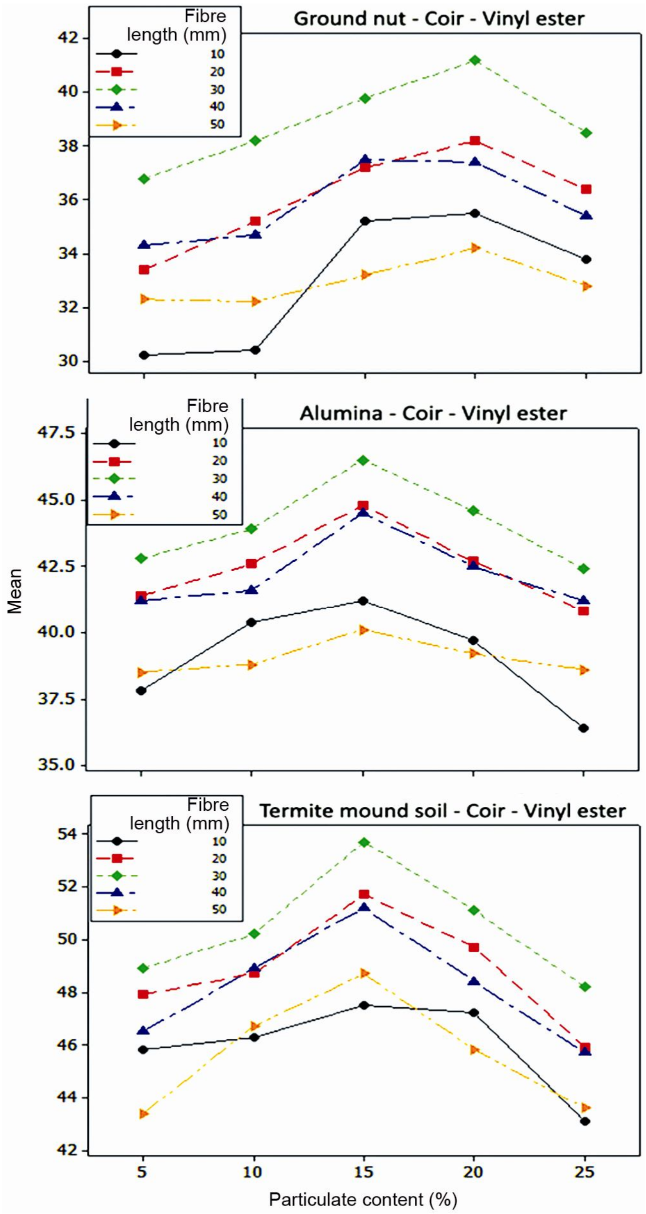

Fig.3—Interaction plots for bio particulated coir-vinyl ester composites

mound soil impregnated coir-vinyl ester composites is found to be 52.1 kJ/m^2 at the fabrication parameters of 28.5 mm fibre length, 16 % particulate content and 24 % fibre content.

3.6 Post Analysis

The results obtained from simulated annealing algorithm are validated by conformance checking using post analysis. The composites are prepared for the optimum conditions and tested. The comparison of experimental values and optimum results obtained by simulated annealing algorithm are given in Table 2. The variations in impact strength values of 0.5 kJ/m^2, 0.6 kJ/m^2 and 0.4 kJ/m^2 are obtained for groundnut, alumina and termite mound soil impregnated coir-vinyl ester composites respectively. The impact behaviors are modeled using non linear equations and the exact value is predicted by post analysis using optimum solutions obtained from simulated annealing in order to finalize the optimum conditions. The values of contour lines and the shape of polynomial equations are shown in Fig. 5. The optimum values of impact behaviors are represented within the maximum contour line and oval shapes are obtained in the better contour surfaces.

Table 2—Post analysis results

Fibre length mm	Particulate content wt %	Fibre content wt %	Impact strength, kJ/m^2					
			Experimental value			Optimum value by SA		
			gn	*al*	*tms*	*gn*	*al*	*tms*
25.0	20.3	10.7	40.0	-	-	39.5	-	-
33.0	16.2	23.8	-	45.3	-	-	45.9	-
28.5	16.0	24.0	-	-	52.5	-	-	52.1

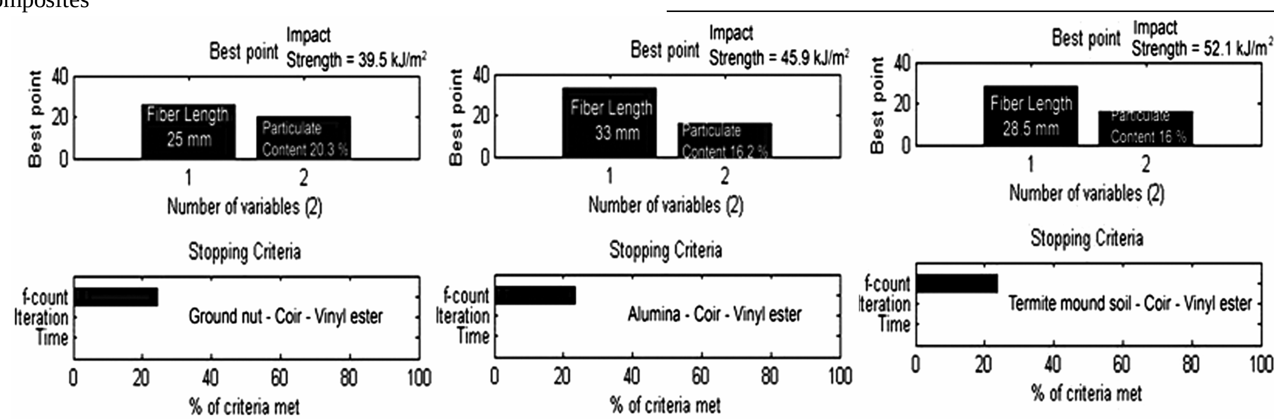

Fig.4—Simulated annealing results for bio particulated coir-vinyl ester composites

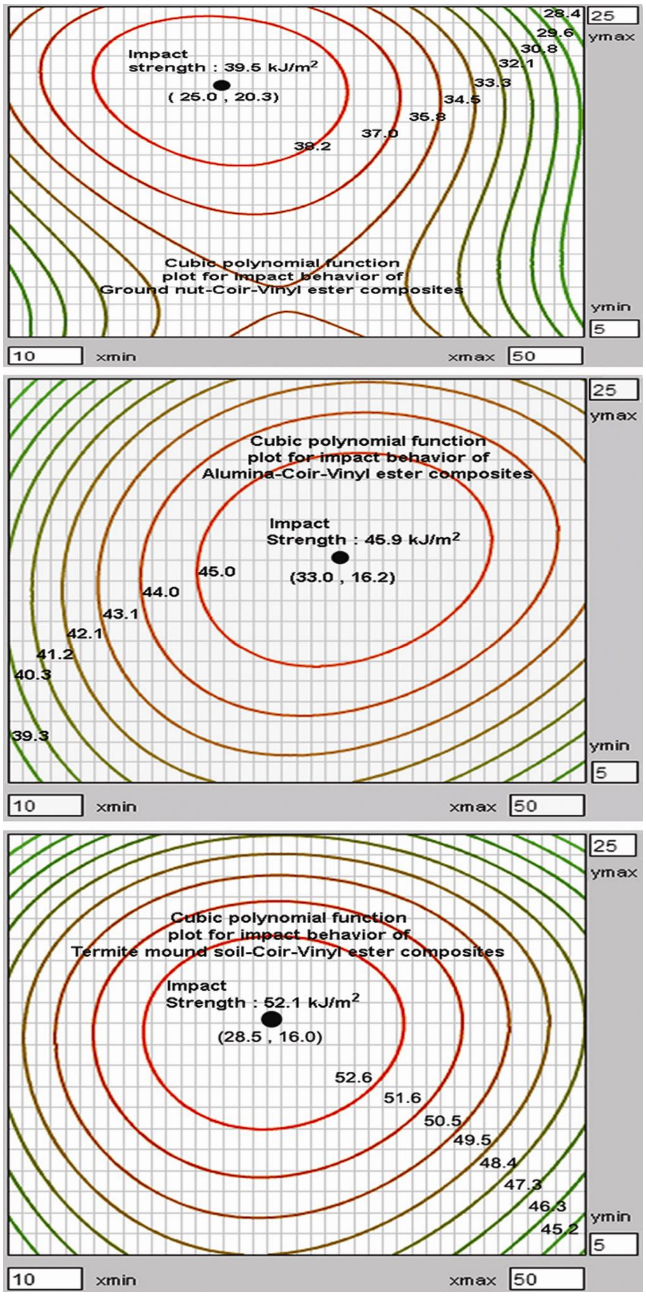

Fig.5—Post analysis contour plots for bio particulated coir-vinyl ester composites

4 Conclusion

The particulates such as groundnut, alumina and termite mound soil have successfully used for the fabrication of coir-vinyl ester composites. The nonlinear regression models developed for the impact strength behaviors of ground nut, alumina and termite mound soil particulated coir-vinyl ester composites are found to be recognizable and the co-efficient of correlation is more than 0.9 for all the impact models. The optimum values of impact behaviors of 39.5, 45.9 and 52.1 kJ/m^2 are obtained using simulated annealing algorithm for groundnut shell, alumina and termite mound soil impregnated coir-vinyl ester composites respectively. The conformance checking is carried out using post analysis by comparing with the experimental results and the variations of impact property values are within 1.5 % only. This specific investigation provides a new platform for the development of bio-particle impregnated natural fibre – polymer composites.

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