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# MECHANICAL CHARACTERIZATION AND ANALYSIS OF RANDOMLY DISTRIBUTED SHORT BANANA FIBER REINFORCED EPOXY COMPOSITES

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***Abstract:*** *Short banana fiber reinforced composites have been prepared in laboratory to determine mechanical properties. It has been observed that as soon as the percentage of the banana fiber increases slightly there is a tremendous increase in ultimate tensile strength, % of strain and young modulus of elasticity. Reinforcement of banana fibers in epoxy resin increases stiffness and decreases damping properties of the composites. Therefore, 2.468% banana fiber reinforced composite plate stabilizes early as compared to 7.7135 % banana fiber reinforced composite plate but less stiff as compared to 7.7135 % banana fiber reinforced composite plate.*

***Keywords:*** *banana fiber, epoxy resin, multi quadric radial basis function method, damping properties, stiffness.*

## 1. INTRODUCTION

The popularity of the natural fiber-reinforced composites is increasing day by day. These composites possess high strength and stiffness for a given weight of material. Natural fiber-reinforced composites are the best alternative to synthetic fibers. The advantages of natural fiber-reinforced composites as compared to synthetic fiber-reinforced composites are clear: they are environmental friendly [1-4] and available in abundance quantity. Natural fibers like bamboo, coir, sisal and waste cellulosic products like wood flour are an effective reinforcement in thermoset and thermoplastic composites [5-8].

In tropical countries fibrous plants like banana, pineapple and coconut are available in abundance. Banana fiber is prepared from waste product of banana cultivation. Therefore banana fibers can be used for industrial applications without spending any extra cost. Banana fiber is good for natural resilience, durability, and resistance to dampness, fungal and bacterial decomposition. Banana fiber can be used for making lightweight composites. Banana fiber is found to be an effective reinforcement in polyester matrix [9]. Kumar and Misra [10] studied the behavior of banana fibers reinforced low-density polyethylene / polycaprolacton composites.

Dynamic analyses have been widely applied to determine the stiffness and damping characteristics of composite structures. It is an effective method when determined over a wide range of stress, temperature and phase composition of fiber reinforced composites. Bledzki and Zhang [11] analyzed the dynamic response of jute fiber reinforced epoxy foams. Huang [12] determined the dynamic behavior of laminated composite plates. Saha et al. [13] studied the damped response of chemically treated and untreated jute-polyester composite. In his paper Amash and Zugenmaier [14] have reported that by incorporation of cellulose fiber, the damping properties of a polypropylene/cellulose composite decreases and stiffness improves.

Various analytical methods like Fourier series, Rayleigh-Ritz, Levy type solution have been developed for analysis of composite plates and laminates. It is known that analytical solutions for isotropic plate problems have been presented for simple plate geometries and boundary conditions. Difficulty increases for getting the analytical solutions of orthotropic and anisotropic plates and laminates. Analytical solutions cannot be obtained when the problems involve complex geometries and boundary conditions. Therefore, numerical methods are used, which are capable of solving such types of problems.

In recent years, meshless techniques have attracted the attention of researchers. In meshless techniques a set of scattered nodes are used instead of meshing the domain. Over the last 20 years, the radial basis functions are considered as powerful technique for scattered data interpolation. The use of radial basis functions as a meshless procedure for numerical solutions of composite plates and laminates is based on the collocation scheme. Due to the collocation technique, this method does not need to evaluate any integral. The main advantage of the radial basis functions (RBFs) over traditional techniques is the meshless property of these methods. The RBFs that depend on shape parameters and distance between nodes mainly include multi-quadrics (MQ), thin plate splines (TPS), Gaussians.

In 1971, Hardy [15] applied the MQRBF for scattered data interpolation. Later on Franke [16] studied the evaluation of RBF's for scattered data interpolation in terms of timing, accuracy and ease of implementation. Kansa [17] developed the concept of solving partial differential equations using radial basis function (RBF). In 2008, Misra et al [18-19] used this method for the analysis of anisotropic plates and laminate, Misra and Chandan Datta [20] applied this method to predict the mechanical behavior of unidirectional glass fibers reinforced Resell/VAC-EHA composites at different volume fraction of fibers.

In this paper, after fabrication and evaluation of mechanical properties of randomly distributed short banana fiber reinforced epoxy resin composite plate, meshless multiquadric radial basis function (MQRBF) method is applied to determine static and dynamic response.

## 2. EXPERIMENTAL STUDIES

### 2. 1. Materials

The banana fiber (BF) bundles were obtained from Regional Research Laboratory (CSIR) Jorhat, India and epoxy resin (araldite LY 556) and hardener (HY 951) were procured from Singhania & Sons Private Limited, Kolkata -700 017.

### 2. 2. Procedure for Short Banana Fiber Reinforced Epoxy Composites Preparation

In order to separate the individual fiber from the bundle, organic solvents such as acetone, toluene, and petroleum ether were used. Better separation of fibers was achieved by using toluene followed by washing with petroleum ether. For this purpose a bundle of fibers were dipped in toluene for 4 hour and then placed in petroleum ether overnight. The solvent was removed and the fibers were dried in air atmosphere.

Liquid epoxy resin (Araldite) and hardener in 1:0.1 ratio was taken in a plastic container and mixed thoroughly for 15 min. For composite preparation, short banana fiber was added to it. It was then initially kept at room temperature for about 24 hours and then heated at 80 0C for 4 hours. Thus, the samples were produced.

### 2. 3. Mechanical Properties

An Instron universal-testing machine (United Kingdom, model-3366) was used for measuring the tensile properties like tensile strength, tensile modulus etc. ASTM D 638 method was followed. A 50 N load cell with crosshead speed of 5mm/min was maintained. All testing were conducted under ambient conditions in an environmentally controlled room. The samples for tensile measurements were cut in a dumbbell shape of 50mm in gauge length, 10 mm in width and 2 mm in thickness. The standard specimens were visually inspected before measurement and were found to be free from pores and nicks. Six samples were taken for each measurement. The flexural strength was determined using the above-mentioned universal testing machine as per ASTM D 792 procedure. Tensile properties of the randomly distributed short banana fibers reinforced epoxy resin composite are shown in Table.

## 3. THEORETICAL ANALYSIS

After evaluating the mechanical properties of the randomly distributed short banana fibers reinforced epoxy composite plate, multiquadric radial basis function method is applied for static and dynamic analyses.

### 3. 1. The Multiquadric Radial Basis Function Method

Consider a general differential equation

$$Aw = f(x,y) \quad in \quad \Omega \tag{1}$$

$$Bw = g(x,y) \quad in \quad \partial\Omega \tag{2}$$

Let $\{P_i = (x_i, y_i)\}_{i=1}^{N}$ be N collocation points in the domain Ω of which $\{P_i = (x_i, y_i)\}_{i=1}^{N_I}$ are interior points and $\{P_i = (x_i, y_i)\}_{i=N_I+1}^{N}$ are boundary points. In the MQRBF method, the approximate solution for the differential equation (1) with boundary conditions equations (2) can be expressed as:

$$w(x,y) = \sum_{j=1}^{N} w_j \varphi_j(x,y) \tag{3}$$

with a multiquadric radial basis:

$$\varphi_j = \sqrt{(x-x_j)^2 + (y-y_j)^2 + c^2} = \sqrt{r_j^2 + c^2} \tag{4}$$

where $\{w_j\}_{j=1}^{N}$ are the unknown coefficients to be determined, and $\varphi_j(x_j,y_j)$ is a basis function. Other widely used radial basis functions are:

$\varphi(r) = r^2$ Cubic

$\varphi(r) = r^2 \log(r)$ Thin plate splines

$\varphi(r) = (1-r)^m + p(r)$ Wendland functions

$\varphi(r) = e^{-(cr)2}$ Gaussian

$\varphi(r) = (c^2 + r^2)^{-1/2}$ Inverse multiquadrics

Here $r = p - p_j$ is the Euclidean norm between points $p(x,y)$ and $p_j = (x_j,y_j)$. The Euclidean distance $r$ is real and nonnegative. $c$ is a shape parameter. In MQRBF method, shape parameter plays an important role for getting the numerical solutions of composite plates and laminates. Small shape parameters are used on the interior, but much larger ones on the boundary [21]. In two-dimensional problems, shape parameter for interior points is given by $c(interior)=2/(N)^{1/2}$ , and shape parameter for boundary points $c(boundary\ points)=(100x200)xc(interior)$ . This is collocation-based method; therefore, domain is discretized into number of points. As number of point's increases in the domain, shape parameter decreases.

## 4. RESULTS AND DISCUSSION

Figure 1 and 2 shows the tensile strength and tensile modulus of the randomly distributed short banana fiber reinforced composites at different % of the fibers. It is observed that as soon as % of the coir fiber increases from 0 to 7.7%, tensile strength and tensile modulus increases. Initially tensile strength increases at fast rate but as soon as coir fiber increases more than 4 %, tensile strength increases at slower rate.

Tensile strain of the randomly distributed short banana fiber reinforced composites at different % of the banana fibers has been shown in figure 3. Variation in % of the strain is high from 2.4% to

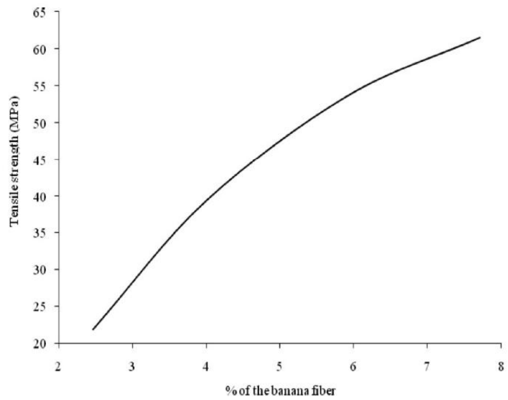


**Fig. 1.** Tensile strength of the randomly distributed short banana fiber reinforced composites at different % of the fibers

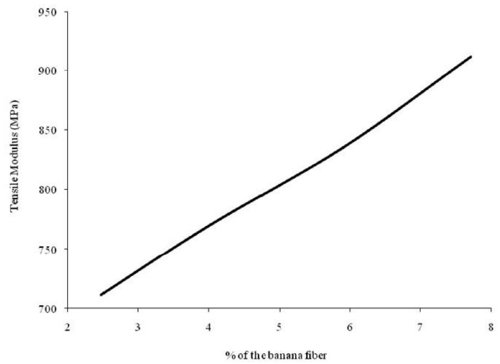


**Fig. 2.** Tensile Modulus of the randomly distributed short banana fiber reinforced composites at different % of the fibers

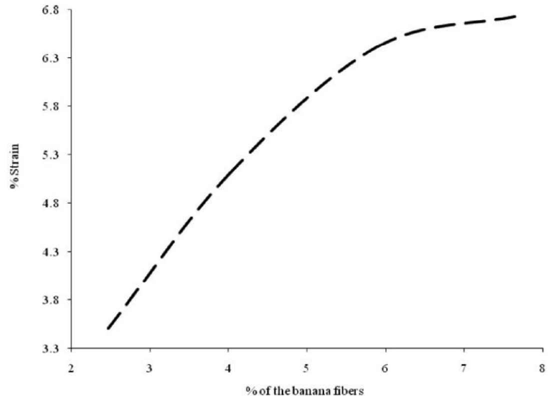


**Fig. 3.** Tensile strain of the randomly distributed short banana fiber reinforced composites at different % of the fibers

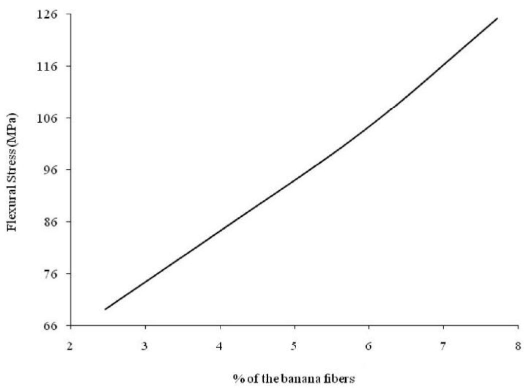


**Fig. 4.** Flexural stress of the randomly distributed short banana fiber reinforced composites at different % of the fibers

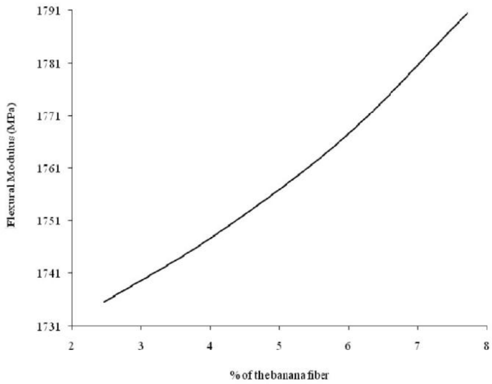


**Fig. 5.** Flexural Modulus of the randomly distributed short banana fiber reinforced composites at different % of the fibers

5.9%, but it is low from 5.9 % to 7.7%. At 5.9 % and 7.7% of the banana fibers, % of strain is 6.42 and 6.74 respectively.

Flexural stress, flexural modulus and flexural strain of the randomly distributed short banana fiber reinforced composites at different % of the banana fibers have been shown in figure 4, 5 and 6 respectively. In this case also as soon as % of the banana fiber increases, flexural stress, flexural modulus and strain increases.

Figure 7 shows the impact strength of the randomly distributed short banana fiber reinforced composites. It is observed that upto 4% banana fibers, impact strength decreases. But as soon as % of the banana fiber increases more than 4%, impact strength increases. When % of the banana is less, matrix plays important role. But as soon as % of the banana fiber increases, fiber plays important role. Fiber increases the strength of the composites. Due to this reason, at higher % of the banana fiber, composite liberate more energy in impact.

Change of mass due to absorption of water in randomly distributed short banana fiber reinforced composites has been shown in figure 8. It is observed that when % of the banana fibers increases in banana fiber reinforced composites, absorption of the water increases. After seven days, absorption of the water in 2.4%, 4.01% and 5.89% banana fiber reinforced composites are

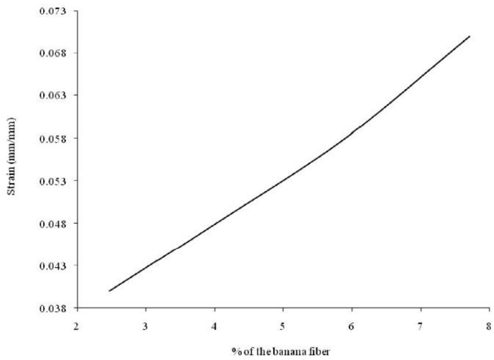


**Fig. 6.** Flexural strain of the randomly distributed short banana fiber reinforced composites at different % of the fibers

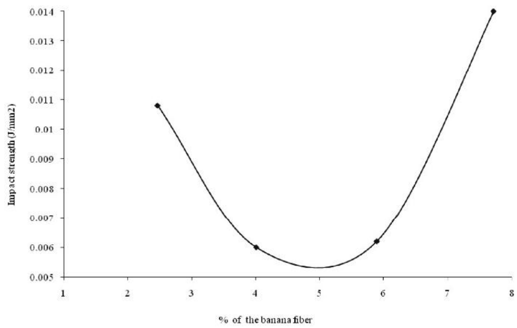


**Fig. 7.** Impact strength of the randomly distributed short banana fiber reinforced composites at different % of the fibers

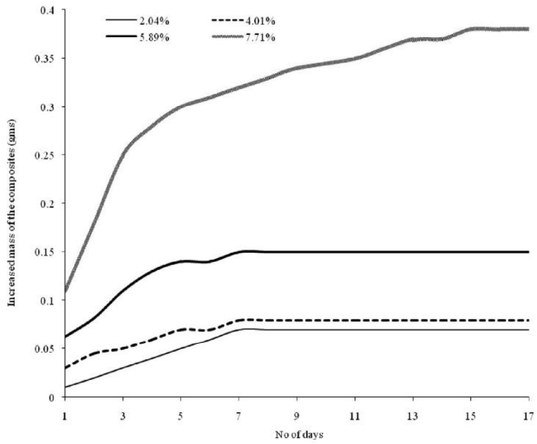


**Fig. 8.** Change of mass of the randomly distributed short banana fiber reinforced composites after putting in water

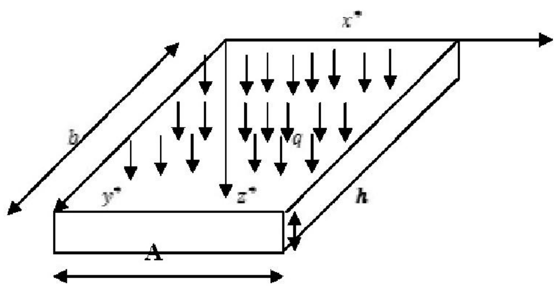


**Fig. 9.** Geometry of the randomly distributed short banana fiber reinforced composite plate

0.07, 0.08 and 0.15 grams respectively. Absorption of the water stops after seven days in these composites. But 7.71 % banana fiber reinforced composite stops absorbing the water after 14th days. It absorbs 0.38 grams water.

**Case Study: Static and Dynamic Response of the Short Banana Fiber Reinforced Epoxy Composite Plate**

Figure 9 shows the geometry, coordinate system and loading in randomly distributed short banana fiber reinforced epoxy composite plate. Neglecting the transverse shear and rotary inertia, governing equation of the plate is expressed in non-dimensional form as:

$$(w_{xxxx} + 2R^{2}w_{xxyy} + R^{4}w_{yyyy}) + w_{tt} + C_v w_t - Q(x,y,t) = 0 \qquad (5)$$

where the subscript denotes the partial derivative with respect to the suffix following. The non-dimensional quantities are defined by

$$w = \frac{w^*}{h}, x = \frac{x^*}{a}, y = \frac{y^*}{b}, R = \frac{a}{b}, t = t^*\sqrt{\frac{D}{\rho a^4 h}}, \quad Q = q(x,y,t)a^4/(Dh)$$

$$C_v = \left(\frac{C_v^*}{M\sqrt{(\rho a^4 h)/D}}\right), m = \rho abh, \quad q(x,y,t) = q_0 . F(t),$$

$$F(t) = \{1, 0 \le t\} \qquad \text{Rectangular Step Loading}$$

$$F(t) = \begin{cases} 1, 0 & \le t \le t_1 \\ 0, & t > t_1 \end{cases}, \; t_1 = 3 \qquad \text{Rectangular pulse loading} \qquad (6)$$

**Boundary Conditions:**

**(a) Simply supported boundary conditions are:**

x=0,1 $w=0$ (7a)

x=0,1 $w_{xx}=0$ (7b)

y=0,1 $w=0$ (7c)

y=0,1 $w_{yy}=0$ (7d)

**(b) Clamped edge boundary conditions are:**

x=0,1 $w=0$ (8a)

x=0,1 $w_x=0$ (8b)

y=0,1 $w=0$ (8c)

y=0,1 $w_y=0$ (8d)

**(c) For initial conditions at t=0:**

$$w = 0\,, \quad \frac{\partial w}{\partial t} = 0\,, \quad \frac{\partial^2 w}{\partial^2 t} = 0 \tag{9}$$

The governing equation (5) is solved using multiquadric radial basis function and boundary conditions, equations (7) and (8), for simply supported and clamped edge plates respectively, and has been presented in Appendix A

In this collocation method, the domain is discretized into n × n grid points. Inside the domain, there are (n − 2) × (n − 2) grid points and the remaining grid points are at the boundaries. There are eight boundary conditions: four boundary conditions for x and four for y. The governing equations generate $(n-2)^2$ equations and every boundary condition creates n equations. Therefore, the total number of equations becomes $(n-2)^2 + 8n$. Since the total number of unknown coefficients is $n^2$, the number of equations is more than the number of unknown coefficients. Hence this method creates ill-conditioning. To overcome this ill-conditioning, multiple linear regression analysis (Appendix B) based on least-square error norms is employed.

Table 1 and 3 shows the deflection of the simple supported and clamped edge randomly distributed short banana fiber reinforced composite plate at various aspect ratios. There is good agreement in MQRBF and Timoshenko [22] results. When aspect ratio increases, deflection decreases due to decrease in load. Deflection of the clamped edge plate is less as compared to simple supported plate.

Deflection of the simple supported randomly distributed short banana fiber reinforced composite plate at different % of the banana fibers has been shown in Table 2 and figure 10. Present results are very near to the reference results. The following features are observed after analyzing the Table 2 and figure 10 for simple supported boundary conditions:

1. 2.468 % short banana fiber reinforced epoxy composite plate gives maximum deflection and 7.713% short banana fiber

**Table 1.** Deflection of the simple supported randomly distributed short banana fibers reinforced composite plate at 2.468 % volume fraction of the fibers

| $q(N/m^2)$ | b(mm) | a(mm) | b/a | h(mm) | Analytical Method [22] $w_{max}$ (mm) | MQRBF Method $w_{max}$ (mm) |
|---|---|---|---|---|---|---|
| 10 | 300 | 300 | 1 | 10 | 5.20E-03 | 5.25E-03 |
| 10 | 300 | 150 | 2 | 10 | 8.11E-04 | 8.09E-04 |
| 10 | 300 | 100 | 3 | 10 | 1.93E-04 | 1.93E-04 |

**Table 2.** Deflection of the simple supported randomly distributed short banana fibers reinforced composite plate at different % of the fibers

| q = 10(N/m2) | Volume fraction of banana fiber in percentage (%) | Analytical Method [22] $w_{max}$ (mm) | MQRBF Method $w_{max}$ (mm) |
|---|---|---|---|
| a=b=300mm | 2.47% | 5.20E-03 | 5.23E-03 |
| h=10mm | 4.01% | 4.80E-03 | 4.82E-03 |
| | 5.90% | 4.43E-03 | 4.45E-03 |
| | 7.71% | 4.06E-03 | 4.08E-03 |

**Table 3.** Deflection of the clamped edge randomly distributed short banana fibers reinforced composite plate at 2.468 % volume fraction of the fibers

| q(N/m$^2$) | b(mm) | a(mm) | b/a | h(mm) | Analytical Method [22] $w_{max}$ *(mm)* | MQRBF Method $w_{max}$ *(mm)* |
|---|---|---|---|---|---|---|
| 10 | 300 | 300 | 1 | 10 | 1.61E-03 | 1.54E-03 |
| 10 | 300 | 150 | 2 | 10 | 1.76E-04 | 1.66E-04 |
| 10 | 300 | 100 | 3 | 10 | 4.02E-05 | 3.95E-05 |

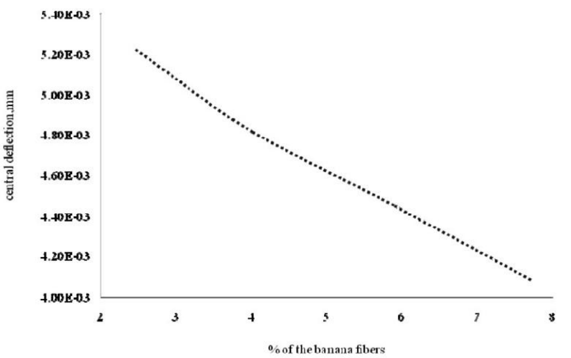


**Fig. 10.** Deflection of the simple supported randomly distributed short banana fiber reinforced composite plate at different % of the fibers

reinforced epoxy composite plate gives least deflection. It means strength of the 2.468 % short banana fiber reinforced epoxy composite plate is least and 7.713% short banana fiber reinforced epoxy composite plate is maximum.

2. As soon as percentage of the banana fiber increases in short banana fiber reinforced composite plate, deflection decreases.

Similar behavior is observed at clamped edge boundary conditions as shown in Table 4 and figure 11, but clamped edge plate deflect less as compared to simple supported plate. Clamped edge plate is more rigid compared to simple supported plate.

A computer program based on the finite difference method (FDM) proposed by Chandrasekhar [23] is also developed. The dynamic response of the simple supported randomly distributed short banana fiber reinforced epoxy composite plate obtained by the present method and finite difference method has been compared and shown in figure 12 at uniformly distributed load q = 10 (N/m$^2$), sides a = b = 300 (mm) and thickness h = 10 (mm). There is good agreement in the results. The following features are observed after analyzing the figure 13-16 for the simple supported boundary

**Table 4.** Deflection of the clamped edge randomly distributed short banana fibers reinforced composite plate at different % of the fibers

| q = 10(N/m2) | Volume fraction of banana fiber in percentage (%) | Analytical Method [22] $w_{\max}$ (mm) | MQRBF Method $w_{\max}$ (mm) |
|---|---|---|---|
| a=b=300mm | 2.47% | 1.61E-03 | 1.54E-03 |
| h=10mm | 4.01% | 1.49E-03 | 1.42E-03 |
| | 5.90% | 1.37E-03 | 1.31E-03 |
| | 7.71% | 1.26E-03 | 1.20E-03 |

condition:

1. When the damping coefficient increases from 1.25–12, non-dimensional maximum deflection decreases in randomly distributed short banana fiber reinforced epoxy composite.
2. At damping coefficient factor Cv = 1.25, 6, and 12, the non-dimensional maximum deflections are 0.0007249, 0.0007147 and 0.0006939 respectively in randomly distributed 2.468 % short banana fiber reinforced epoxy composite plate at rectangular step loading.
3. 2.468 % short banana fiber reinforced epoxy composite plate stabilizes early as

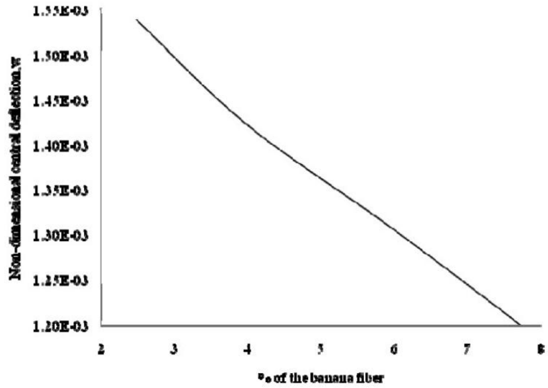


**Fig. 11.** Deflection of the clamped edge randomly distributed short banana fiber reinforced composite plate at different % of the fibers

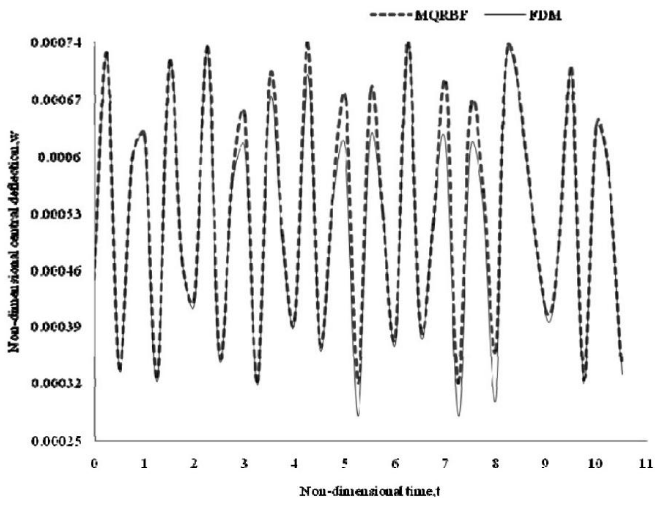


**Fig. 12.** Dynamic response of the simple supported randomly distributed short banana fiber reinforced epoxy composite plate at uniformly distributed load q =10 N/m2and 2.468% of the banana fibers (Rectangular step loading condition).

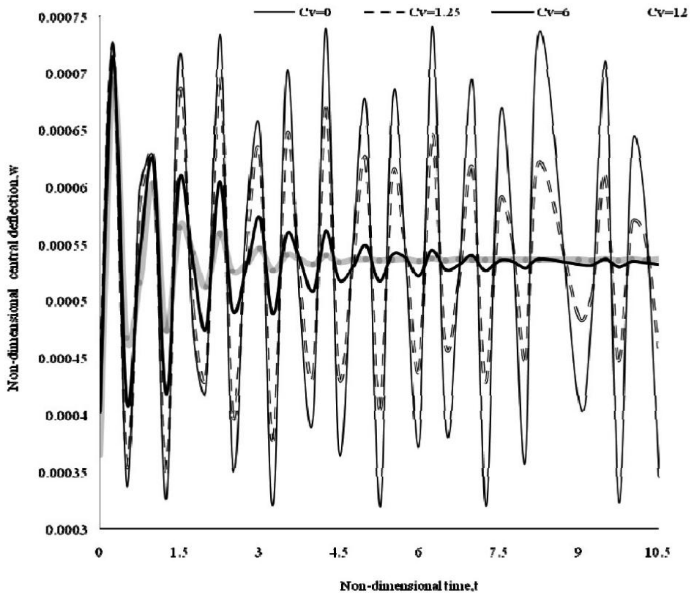


**Fig. 13.** Damped response of the simple supported randomly distributed short banana fiber reinforced epoxy composite plate at uniformly distributed load q =10 N/m$^2$ and 2.468 % of the banana fibers at various damping coefficient factor (rectangular step loading condition).

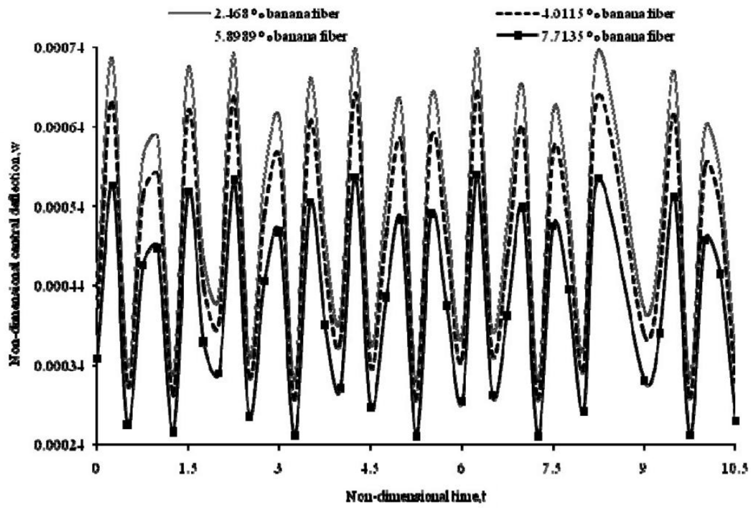


**Fig. 14.** Dynamic response of the simple supported randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular step loading).

compared to 7.713 % but deflect more at rectangular step loading.

4. After Non-dimensional time 3, there is sudden change in maximum non-dimensional deflection. It is very less after Non-dimensional time 3 due to rectangular Pulse loading.
5. 2.468 % short banana fiber reinforced epoxy composite plate stabilizes after Non-dimensional time 7.5 at damping coefficient factor 12. But it does not stabilize at Cv=1.25 and 6 after non-dimensional time 10.5 at rectangular pulse loading.

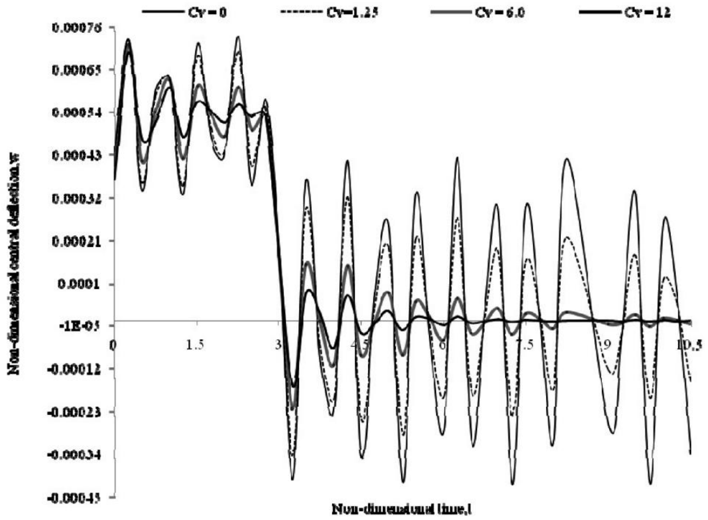


**Fig. 15.** Non-dimensional centre deflection versus Time for damped response of simple supported randomly distributed 2.468 % short banana fiber reinforced epoxy composite plate at various damping coefficient factor (Rectangular Pulse loading condition).

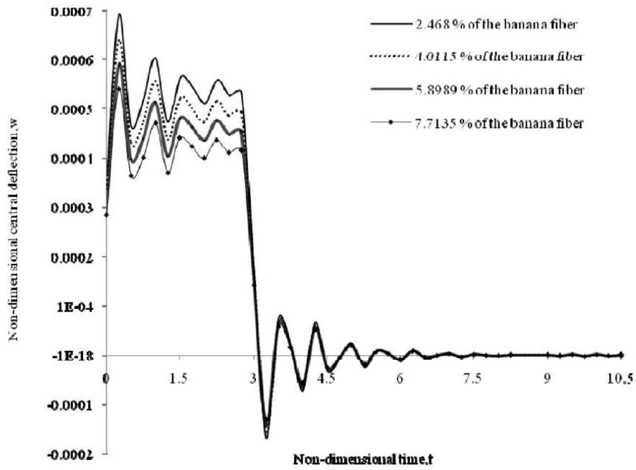


**Fig. 16.** Non-dimensional centre deflection versus Time for damped response of simple supported randomly distributed short banana fiber reinforced epoxy composite plate at various % of the banana fiber (Rectangular Pulse loading condition: damping coefficient factor Cv = 12 ).

6. In rectangular step loading, loads dominate over stiffness of the plate. Therefore, plate deflects downwards and deflection is positive. But in rectangular pulse loading after non-dimensional time 3, stiffness of the plate dominates and visco-elastic internal forces apply in upward direction. Therefore, plate deflects upwards and negative deflection also appears with positive deflection.

Similar behavior is observed at clamped edge boundary conditions as shown in Figure 17 and 18. But clamped edge plate takes more time to stabilize as compared to simple supported plate because clamped edge plate dissipate less energy and second important point is, maximum non-dimensional deflection is less in clamped edge plate as compared to simple supported plate.

Figure 19-20 shows the non-dimensional transverse velocity of simple supported randomly distributed short banana fiber reinforced

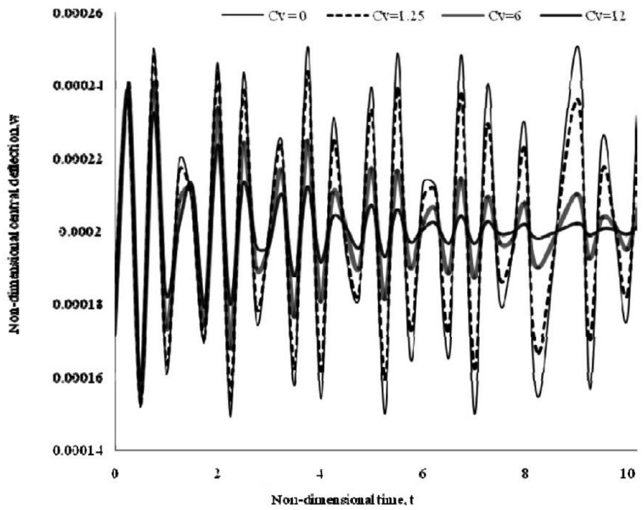


**Fig. 17.** Damped response of the clamped edge randomly distributed short banana fiber reinforced epoxy composite plate at uniformly distributed load q =10 N/m$^2$ and 2.468% of the banana fibers at various damping coefficient factor (rectangular step loading condition).

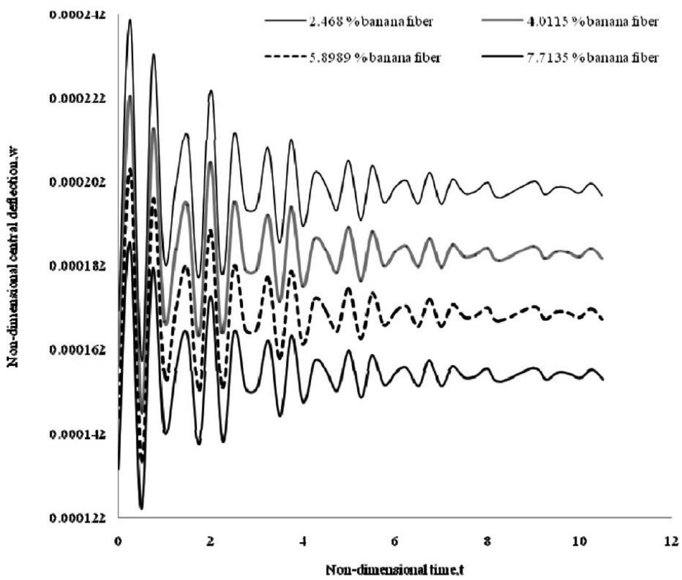


**Fig. 18.** Dynamic response of the clamped edge randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular step loading).

composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber.

It is observed that rectangular pulse loading short banana fiber reinforced composite plate gives maximum transverse velocity compared to rectangular step loading short banana fiber reinforced composite plate. Due to effect of rectangular pulse loading, value of transverse velocity of the plate is more in upward direction compared to downward direction. Transverse velocity of the 2.468 % short banana fiber reinforced composites is higher compared to 7.7135 % short banana fiber reinforced composites.

Transverse-velocity of the clamped edge randomly distributed short banana fiber

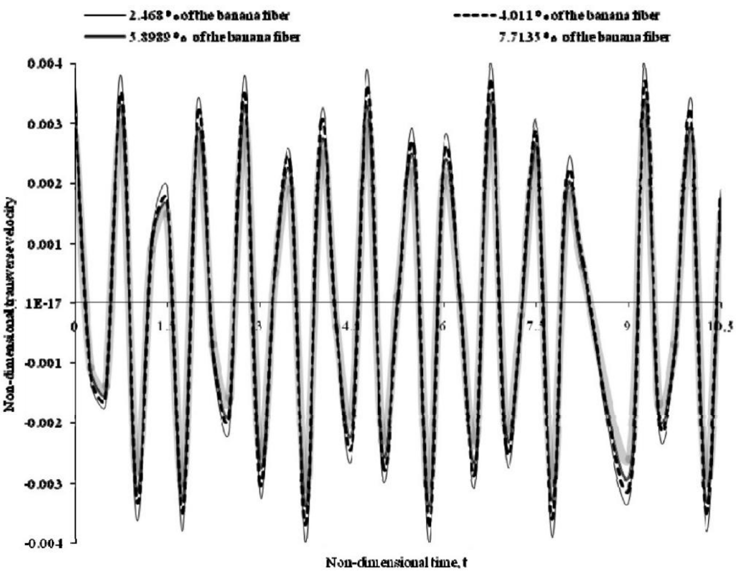


**Fig. 19.** Transverse-velocity of a simple supported randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular step loading).

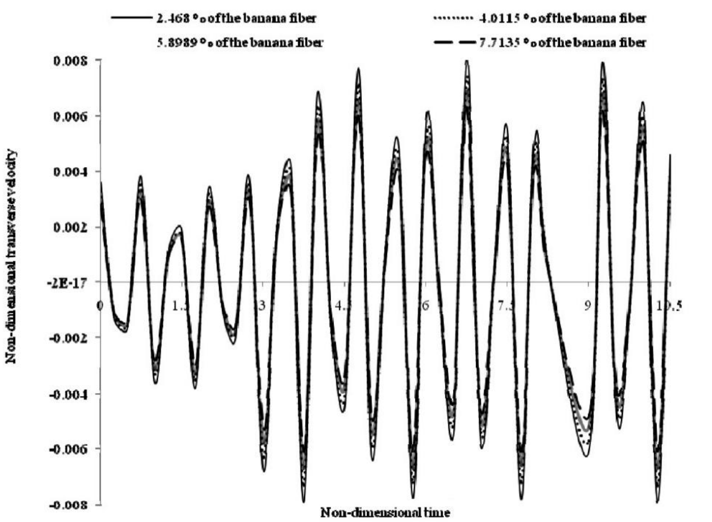


**Fig. 20.** Transverse-velocity of a simple supported randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular pulse loading).

reinforced composite plate has been shown in Figure 21. Transverse velocity is less in clamped edge plate as compared to simple supported plate.

Figure 22-23 shows the non-dimensional transverse acceleration of a simple supported short banana fiber reinforced composite plate. It is observed that initially acceleration is less but after non-dimensional time 3, acceleration increases in rectangular pulse loading short banana fiber reinforced composite plate. Transverse acceleration of the rectangular pulse loading short banana fiber reinforced composite plate is much higher compared to rectangular step loading short banana fiber reinforced composite

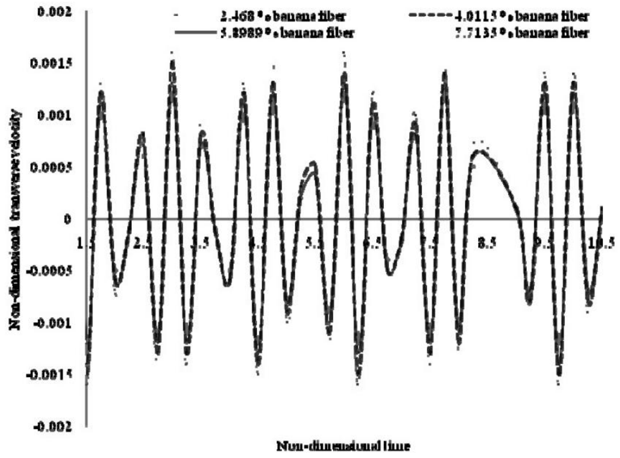

**Fig. 21.** Transverse-velocity of a clamped edge randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular step loading).

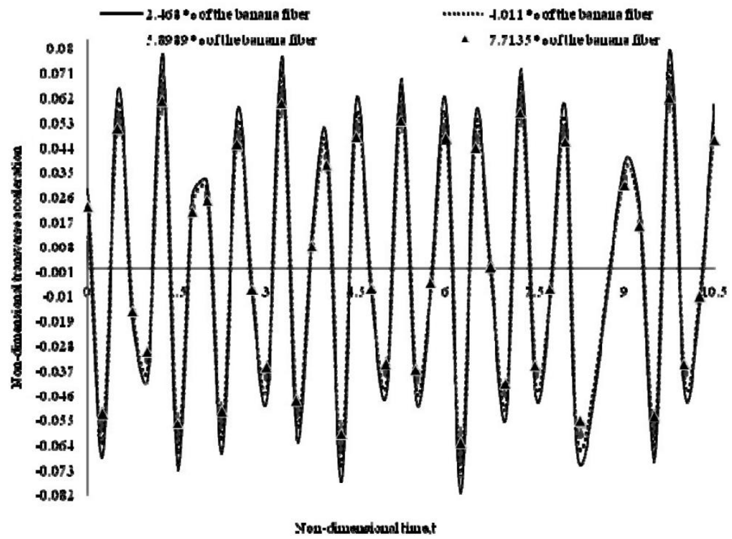

**Fig. 22.** Transverse-acceleration of a simple supported randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 N/m$^2$ and different % of the fiber (rectangular step loading).

plate. Similar behavior is observed of the rectangular step loading short banana fiber reinforced composite plate at clamped edge boundary conditions as shown in Figure 24.

Two factors plays important role for variation in velocity and acceleration. One is uniformly distributed load which always act downwards and other is visco-elastic internal forces of the composite plate which act opposite to uniformly distributed load. It tries to give upward motion. Due to this reason, there is variation in velocity and acceleration.

## 5. CONCLUSION

Randomly distributed short banana fiber reinforced composite plates have been prepared in laboratory at different volume fraction of the banana fibers for the

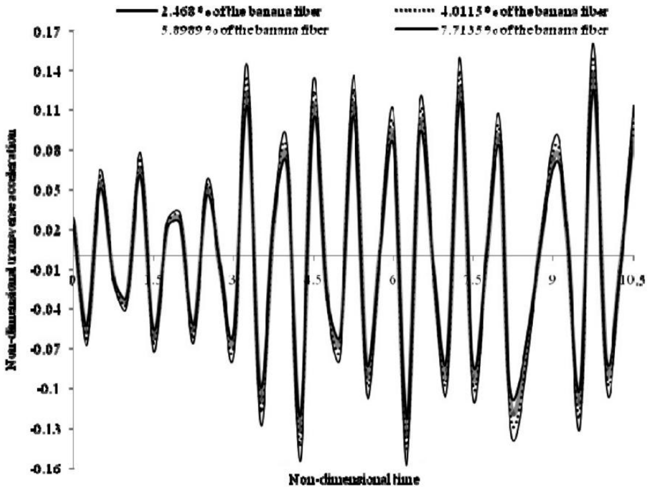


**Fig. 23.** Transverse-acceleration of a simple supported randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 $N/m^2$ and different % of the fiber (rectangular pulse loading).

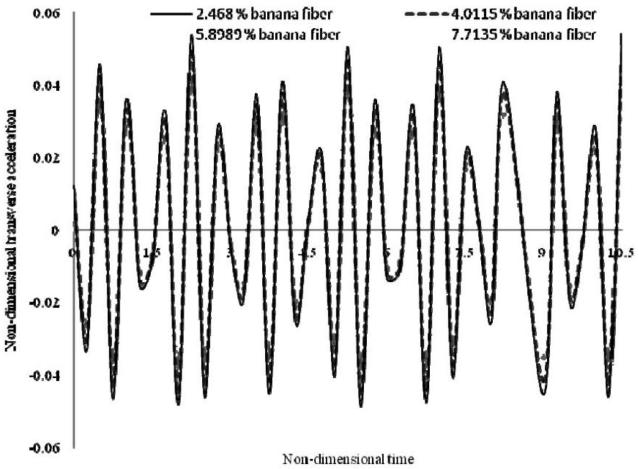


**Fig. 24.** Transverse-acceleration of a clamped edge randomly distributed short banana fiber reinforced composite plate at uniformly distributed load q = 10 $N/m^2$ and different % of the fiber (rectangular step loading).

evaluation of mechanical properties. Theoretical static and dynamic analyses of the composite plate have also been presented in this work.

As soon as percentage of the banana fibers increases, ultimate tensile strength and modulus of elasticity of the banana fiber reinforced composite plate increases. Initially, Impact strength of the banana fiber reinforced composite plate decreases up to 4% of the banana fibers, but as soon as % of the banana fiber increases more than 4%, impact strength increases.

As soon as % of the banana fiber increases, absorption of the water also increases. This is the major drawback of the natural fiber reinforced composites. After absorbing the water, there tensile strength decreases.

Furthermore, meshless multi quadric radial basis function method has also been applied to predict the static and transient response of the composite plates at rectangular step and pulse loading. In this collocation method, the number of equations generated is more than the number of unknowns. Therefore, multiple regression analysis is used to overcome this incompatibility. This method is found to be effective in static and dynamic response of the composite plates.

## APPENDIX

### A. Notations

| | |
|---|---|
| $a,b$ | Dimension of plates |
| $h$ | Thickness of plates |
| $R$ | Aspect ratio (a/b) |
| $\theta$ | Poisson's ratio |
| $\rho$ | Mass density of plates |
| $m$ | Mass of the plates |
| $C^*_v$, $C_v$ | Viscous damping, dimensionless viscous damping |
| $D$ | Flexural rigidity of the composite plates |
| $E$ | Young's modulus of the composite materials |
| $G$ | Shear modulus of the composite materials |
| $q$, $Q$ | Transverse load, dimensionless transverse load |
| $t^*$, $t$ | Time, dimensionless time |
| $w^*$ | Displacement in direction |
| $w$ | Dimensional splacement in z direction |

### B. Multiquadric radial basis function method for governing differential equation

Substitution of multiquadric radial basis function in equation (5) gives

$$\left(\sum_{j=1}^{N} w_j \frac{\partial^4}{\partial x^4}\emptyset_j + 2R^2 \sum_{j=1}^{N} w_j \frac{\partial^4}{\partial x^2 y^2}\emptyset_j + \sum_{j=1}^{N} R^4 w_j \frac{\partial^4}{\partial y^4}\emptyset_j\right) + \frac{\partial^2 w}{\partial t^2} - C_v \frac{\partial w}{\partial t} - Q = 0 \tag{10}$$

For simple supported edge

$$x=0,a \qquad \sum_{j=1}^{N} w_j \varphi_j = 0 \tag{11a}$$

$$x=0,b \qquad \sum_{j=1}^{N} w_j \varphi_j = 0 \tag{11b}$$

$$x=0,a \qquad \sum_{j=1}^{N} w_j \frac{\partial^2}{\partial x^2}\varphi_j = 0 \tag{11b}$$

$$x=0,b \qquad \sum_{j=1}^{N} w_j \frac{\partial^2}{\partial y^2}\varphi_j = 0 \tag{11b}$$

For clamped edge

$$x=0,a \qquad \sum_{j=1}^{N} w_j \varphi_j = 0 \tag{12a}$$

$$x=0,b \qquad \sum_{j=1}^{N} w_j \varphi_j = 0 \tag{12b}$$

$$x=0,a \qquad \sum_{j=1}^{N} w_j \frac{\partial}{\partial x}\varphi_j = 0 \tag{12b}$$

$$x=0,b \qquad \sum_{j=1}^{N} w_j \frac{\partial}{\partial y}\varphi_j = 0 \tag{12b}$$

### C. Multiple regression analysis

$\boldsymbol{A.a = p}$

where $\boldsymbol{A}$ is $\boldsymbol{(l*k)}$ coefficient matrix, $\boldsymbol{a}$ is $\boldsymbol{(k*1)}$ vector, $\boldsymbol{p}$ is $\boldsymbol{(l*1)}$ load vector. Approximating the solution by introducing the error vector e, we get

$\boldsymbol{p = Aa + e}$

where $\boldsymbol{e}$ is $\boldsymbol{(l*1)}$ vector. To minimize the error norm, let us define a function $\boldsymbol{S}$

$S(a) = e^T e = (p-Aa)^T(p-Aa)$

The least-square norm must satisfy

$(\partial S/\partial a)^a = -2A^T p + 2A^T Aa = 0$

This can be expressed as

$\boldsymbol{a = (A^T A)^{-1}(A^T P)}$

or

$\boldsymbol{a = B \cdot P}$

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