

# Tensile and Buckling Analysis of Polymeric Composite Columns

Dr. Jawad Kadhim Oleiwi  
Department of Material Engineering  
University of Basrah  
College of Engineering  
Jawadkad @ yahoo.com

Dr. Emad Saadi Al- hassani  
Department of Material Engineering  
University of Basrah  
College of Engineering  
Emad2000x @ yahoo.com

Alaa Abd Mohammed  
Department of Material Engineering  
University of Basrah  
College of Engineering  
Alaa\_eng.2010 @ yahoo.com

**Abstract-** This research studied the critical load of composite columns theoretical and numerical by using ANSYS14 package depended on experimental tensile properties of composite specimens. The composite specimens were prepared by hand lay-up technique made from unsaturated polyester reinforced with glass fibers with different fiber volume fraction  $V_f$ , aspect ratio (L/T), and angle of fibers for coarse and fine woven fibers.

The critical load that obtained by using program (ANSYS 14) have also shown a good agreement with results that were obtained theoretically and the maximum difference was (0.7%).

The results show that the maximum value of the critical load can be observed at  $V_f = 11\%$ ,  $L/T = (3.5)$  and  $\theta = (0^\circ/90^\circ)$  for fine woven fibers was (622.115N). Also its found the maximum critical load for coarse woven fibers can be observed at  $V_f = 8\%$ ,  $L/T = (3.5)$  and  $\theta = (0^\circ/90^\circ)$  was (486.887N). Also the observed values of tensile properties and predicated values are scattered close to the (45°) line.

**Keywords:** Polymer composite, ANSYS package, Mathematical model, Columns Buckling.

## I. Introduction

Composite materials can be obtained by combining two constituents: stiff and strong fibers and a matrix in which they are embedded. The fibers are the load carrying elements, whereas the matrix provides protection and support for the fibers and allows the redistribution of the load among adjacent fibers to be obtained [1].

In many engineering structures such as columns, beams, or plates, their failure develops not only from excessive stresses but also from buckling [2].

A beam under axial compressive load can become unstable and collapse. This occurs when the beam is long and its internal resistance to bending moment is insufficient to keep stable. At the critical load the beam became unstable and buckled that a large deflection occurs due to small increase in force, this force called critical load or (buckling load). The equations of the buckling of the column have been derived many years ago and readily variable to design engineers. Columns made of polymer matrix fiber reinforced composite materials are increasingly used in automotive, aerospace, structural and mechanical engineering industries. And buckling loads are important parameter in the design and development of high – performance composite [3].

Seangatith et al in (1999) investigated an experimental of 44 axially loaded GFRP box section columns with pinned-pinned support and with various slenderness ratios ranging from 16.6 to 149.7. The GFRP columns were made of glass fiber reinforced plastic and manufactured by pultrusion process. It has found that the axially loaded GFRP box section columns were failed either in crushing failure due to

a combination of axial load and flexural buckling for short column and in the Euler or flexural buckling for long column [4].

Oleiwi in (2006) has conducted a study deals with the estimation of critical load of the square column made from unidirectional composite of glass fiber – epoxy matrix, Kevlar fiber – epoxy matrix and carbon fiber – epoxy matrix and for different ratios of width to length (h/l) has been carried out using finite element analysis and experimentally. It was found that the value of critical load depends on the type of the composite material [5].

Thuc et al in (2012) illustrated vibration and buckling of cross-ply composite beams using refined shear deformation theory. Numerical results are obtained for composite beams to investigate critical buckling load [6].

Nutakor in (2012) studied the buckling prevention in light weight stiffened structures using a finite element method. The emphasis of the investigation presented to find the critical length at which buckling preventers can be attached along the side of a stiffening beam so it can effectively prevent the stiffened structure from buckling. During the investigation the critical length  $L_c$  was studied as a function of slenderness ratio  $S_r$  of a slender beam. The investigation was conducted to increase in  $L_c$  increases the strain energy capacity of the beam, increase in elasticity modulus  $E$  decreases the strain energy capacity of the beam and increases in  $S_r$  due to the fact that the height of the beam increases will decrease the strain energy capacity of the beam [7].

Priyadarsini et al in (2012) investigated the buckling of fiber reinforced composite. This study details an numerical (FEM) and an experimental study on buckling carbon fiber reinforced plastics (CFRP) layered composite cylinders. The effects of different types of loadings, geometric properties, lamina lay –up and amplitudes of imperfection on the strength of the cylinders under compression are studied [8].

Jadhav et al in (2012) studied the buckling load for different glass fiber orientation laminate to find optimum laminate which can sustain maximum critical buckling load and compare experimental and ANSYS result. The study was conducted to in different fiber direction and load direction for all lamina is decreased then critical buckling load also increases [9].

Ali et al in (2012) illustrated the behavior of slender Partially Encased Composite (PEC) columns under eccentric axial load causing symmetrical single curvature bending. The results show that the axial capacity of a partially encased composite columns are found to decrease significantly as the overall slenderness ratio increases [10]. The aim of this research was to study the influence of volume fraction and orientation of glass fibers on tensile properties and critical load of composite column made from

of unsaturated polyester reinforced by woven fine and coarse fibers.

### 2. Theoretical Background

Column fails by buckling when the axial compressive load exceeds some critical load. The critical load of the composite column can be calculated from the Euler equation as follows [11]:

$$P_{cr} = C \frac{\pi^2 EI}{L^2} \tag{1}$$

Where:-

C: The end condition number, when both end are free to pivot use(C=1).

L: The length of the column (m).

A: Area of cross section (m<sup>2</sup>).

I: Moment of inertia (m<sup>4</sup>).

E: Modulus of elasticity (GPa).

The compressive stress can be well below the material yield strength at the time of buckling the factor that determines if a column is short or long it is slenderness ratio (S) [12]:

Where:-

$$S=L/r \tag{2}$$

and

$$r = \sqrt{\frac{I}{A}} \tag{3}$$

That:

r: Radius of gyration (m).

S: Slenderness ratio.

A short column is usually defined as one whose slenderness ratio is less than about (10).

The major Poisson's ratio is given by:

$$\nu_{ij} = \nu_f V_f + \nu_m V_m \tag{4}$$

It also obeys the rule of mixtures. Further thought will show that the minor Poisson's ratio must be related to  $\nu_{ij}$  by the equation [13]:

$$\frac{\nu_{ji}}{E_j} = \frac{\nu_{ij}}{E_i} \tag{5}$$

Where:-

i, j = 1,2,3,.....,n.

$\nu_{ij}$  :- The Poisson's ratio in the plane (ij).

$\nu_{ji}$  :- The Poisson's ratio in the plane (ji).

$E_i$ :-The modulus of elasticity in the direction (i).

$E_j$ :-The modulus of elasticity in the direction (j).

$V_f, V_m$ :- Volume fraction of each of the fiber and matrix respectively.

To calculate the volume fraction of each of fiber and matrix basis as follows:-

❖ In terms of volume fraction[14]:-

$$V_f = \frac{V_f}{V_c} * 100\% \tag{6}$$

$$V_m = \frac{V_m}{V_c} * 100\% \tag{7}$$

Where:-

$V_c$ :-The volume of the composite material.

### 3. The Mathematical Model

Response surface method (RSM) is a collection of a mathematical and statistical technique that are useful for modeling, analysis and optimizing the process in which

response of interest is influenced by several variables and the objective. In many engineering fields, there is a relationship between an output variable of interest "z" and a set of controllable variables {x, y ... N<sub>n</sub>}. In some systems, the nature of relationship between y and x values might be known. Then, a model can be written in the form [15]:-

$$z = f(x, y, \dots, N) + \epsilon \tag{8}$$

The variables (x, y and N) are independent variables where the response (z) depends on them. The experimental error term, denoted as  $\epsilon$ .

In this study, multiple polynomial (least square fitting) regression analysis is used to establish a mathematical model among the experimentally obtained parameters. Multiple regression analysis techniques are applied to relate the volume fraction and angle of glass fibers for two type (fine and coarse fiber), the best form of the relationship between the property (modulus of elasticity or tensile strength or percentage elongation) with volume fraction and angle of fiber parameters is chosen in the form of [16]:-

$$z = a + b * x + c * y + d * x^2 + e * y^2 + g * x * y \tag{9}$$

Where:-

x:- is the volume fraction of fiber.

y:- is the angle of fiber.

The analysis of variance (ANOVA) is also called coefficient of multiple determination referred to (R) measure the proportionate reduction of total variation in associated with use of the set of predictors in the model ( is used to check the validity of the model) it is defined in terms of SST,SSR, and SSE as [17] :-

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{10}$$

Where:-

SSE:- The sum of squared error.

SSR:-The regression sum of squares.

SST:-The total correct sum of squares.

### 4. Modeling

The following steps represent the procedure of modeling the problem:-

#### 4.1 Build the model

It includes defining element type, element real constants (in this option only model thickness is entered (4mm)), material properties (young's modulus of composite used in this work are determined from tensile test and poissons ratio were calculated theoretically by rule of mixture. Table (3) contains mechanical properties of the composites column of this work), and the model geometry. The element was choose depends on the application, the type of results that needs to be calculated. The element type chosen in this study is (SHELL-281). It is an 8-node element I, J, K, L, M, N, O and P with six degrees of freedom at each node; translations in the x, y, and z axes, and rotations about the x, y, and z-axes, as shown in fig.(3). SHELL-281 is suitable for analyzing thin to moderately-thick shell structures. Most element types require material properties. Depending on the application, material properties can be linear or nonlinear. After defining material properties, the next step in an analysis is generating a finite element model, as show in Fig. (4).

#### 4.2 Meshing

After the model geometry specification completed, the next step is to provide or a finite element mesh for the part. Advances in pre-processor capabilities have greatly increased the ease of creating finite element meshes. This step is automatically generated by using the meshing option in finite element method, as shows in Fig. (5).

#### 4.3 Applied loads and obtain the static solution

In this step defined the analysis type and options, applied load (displacement and pressure), specify load step options, and begin the finite element solution, as show in Fig. (6).

#### 4.4 Obtain the Eigen value buckling solution

This step requires files from the static analysis. Also, the database must contain the model geometry data to obtain the Eigen value buckling solution.

#### 4.5 Expand the solution

This step is used to review the buckling mode shapes.

#### 4.6 Review the results

It consists of buckling load factors, buckling mode shapes, and relative stress in distributions, as show in Fig. (7).

### 5. Experimental Work

Basically two main tasks were carried out to achieve the objectives of study. The first task was the preparation of composite specimens by combining the unsaturated polyester and woven fiber glass (illustrated in Fig. (1)) with different fibers volume fraction (0, 3, 5 & 8 %  $V_f$ ) for coarse fibers and (0, 4, 7 & 11%  $V_f$ ) for fine fibers, and with different angle of fiber ( $0^\circ/90^\circ$ ) and ( $45^\circ/-45^\circ$ ). Then it was continued by performing the tensile and buckling test carried out to determine the characteristics of the studied composite. The usage of unsaturated polyester resin as a matrix was chosen because it is the standard economic resin commonly used, preferred material in industry and besides, it yields highly rigid products with a low heat resistance property. The type of unsaturated polyester resin is provided from the Saudi Arabia Company in the form of transparent viscous liquid at room temperature. The resin was prepared by mixing unsaturated polyester with 2% hardener. The hardener type used is the Methyl Ethyl Keton Peroxide (MEKP). The mechanical properties of unsaturated polyester resin and glass fiber are given in table (1) [18].

#### -Preparation of Composites

The composite specimens were fabricated by using hand lay-up technique. Composites having different fibers content were prepared by varying the type, volume fraction and angle of fibers for fine and coarse woven fibers. In the first process of preparing the composite specimen's preparation process is to set the percentage of fibers content in the composite. The amount of resin needed for each category of composite laminate was calculated after that. Then the resin was mixed uniformly with hardener, the mixture was poured carefully into the moulds and left in the mould for 24 hours. After the composites were fully dried, they were separated off from the moulds, and then put the specimens in oven at ( $55^\circ\text{C}$ ) for (1 hrs) [19].

Specimens are prepared after the composites are ready. The geometry of the specimens for tensile test is set by referring to ASTM standard D- 638 as shown in Fig. (2) [20]. To calculate experimental modulus of elasticity from stress-strain curves applied for composite specimens and this experimental modulus of elasticity used as input data in ANSYS to calculate buckling load. Tensile test is done by using universal testing machine type (LARYEE) with capacity (50 KN) applied load and strain rate (0.5 mm/min). The variables of specimens that are taking in consideration for buckling test are illustrated in table (2).

### 6. Results and Discussion

#### 6.1 Effect of Fiber Volume Fraction and Aspect Ratio of Composite Column on Critical Load for Fine and Coarse Fiber

Fig. s (8-19) show the critical load versus fiber volume fraction of for fine and coarse glass fiber at different aspect ratio of composite column and fiber orientation for numerical (ANSYS 14) and theoretical results as shown in equation (1). It can be seen from these Fig. s the critical load increased as the fiber volume fraction increased because of the glass fiber have stiffness and this lead to increase the stiffness of composite specimens and improved buckling resistance. As anticipated, the fiber volume fraction is represent significant importance factor for improving the buckling resistance. Also it can be seen from these Fig. s when the column length is increased, the buckling resistance is decrease [9 & 21].

It was clearly evident from these Fig. s the results of theoretical and numerical gives a good agreement between them. The maximum difference between theoretical and numerical was (0.7%).

#### 6.2 Numerical Results

Viewing buckled shapes of composite columns is obtained from finite element method in addition to the value of critical load, sample of specimen buckling illustrated in Fig. (7). It has also been found from the numerical results of composite columns for fiber orientation ( $0^\circ/90^\circ$ ) & ( $45^\circ/-45^\circ$ ), that the deformation will be increased when the aspect ratio (L/T) of the composite columns increased. On the other hand the deformation will be decreased when the fiber volume fraction increased. It can be seen that the maximum value of the critical load can be observed at  $V_f = 11\%$ ,  $L/T = (3.5)$  and  $\theta = (0^\circ/90^\circ)$  for fine fiber was (622.115N) see Fig. (11). Also its found the maximum critical load for coarse fiber can be observed at  $V_f \% = 8\%$ ,  $L/T = (3.5)$  and  $\theta = (0^\circ/90^\circ)$  was (486.887N) see Fig. (17).

#### 6.3 Scattering of Mathematical Model for Tensile Results

The validity of regression models developed is further tested by drawing scatter diagrams. Typical scatter diagrams for all the models are presented in Fig. s (20-25). The observed values and predicted values of the responses are scattered close to the ( $45^\circ$ ) line, indicating an almost perfect fit of the developed empirical models [22&23]. The experimental results are modeled using RSM. The Fig. s show coefficient multiple determinations ( $R^2$ ) of the properties as function of ( $x =$  volume fraction of fiber) and ( $y =$  angle of fiber). It can be seen from these models that the volume fraction has greater effect than the angle of fiber on the properties.

## 7. Conclusions

The main conclusions were:-

- 1- The critical load of composite columns will increased with increased fiber volume fraction for two type of glass fiber.
- 2- The fiber orientation ( $0^\circ/90^\circ$ ) have higher critical load than fiber orientation ( $45^\circ/45^\circ$ ) for two type of fiber.
- 3- The value of young's modulus and ultimate tensile strength of specimens increases with increase fiber volume fraction for two type of glass fiber.
- 4- The results of critical load theoretical and numerical gives a good reasonable between them. The maximum difference between theoretical and numerical was (0.7%).

## 8. References

- [1] Pietropaoli E. & Riccia A., "*Finite Element Analysis of the Stability (Buckling and Post-Buckling) of Composite Laminated Structures: Well Established Procedures and Challenges*", Journal of Appl Compos Mater, Vol.(19), PP.(79–96), (2012).
- [2] Gaira N.S., Maurya N.K. & Yadav R.K., "*Linear Buckling Analysis of Laminated Composite Plate*", [IJESAT] International Journal of Engineering Science & Advanced Technology, Vol.(2), Issue (4), PP.(886 – 891), (2012).
- [3] David Bushnell, "*Buckling of Shells-pitfall for Designers*", AIAA 80-0665R, Vol. 19, No. 9, (1981).
- [4] Seangatith S. and Sriboonlue W. , "*Axially Loaded Glass-Fiber Reinforced Plastic Composite Columns*", The Seventh East Asia Pacific Conference on Structural Engineering & Construction, Kochi, Japan, PP.( 1307-12), (1999).
- [5] Oleiwi, j. k. , "*Buckling Analysis of The Composite Column by using Finite Element Method and Experimental Method*", The Iraqi Journal for mechanical and materials engineering, Vol. (6), No. (2), (2006).
- [6] Thuc V. & Fawad I., "*Vibration and Buckling using Refined Shear Deformation Theory*", 2<sup>nd</sup> International Conference on Advanced Composite Materials and Technologies for Aerospace Applications, ISBN 978-0-946881-765, PP. (14-18), (2012).
- [7] Nutakor C., "*Buckling Prevention in Light Weight Stiffened Structure*", Plastics Technology, (2012).
- [8] Priyadarsini Kalyan & Srinivasan S. M., "*Numerical and Experimental Study of Buckling of Advanced Fiber Composite Cylinders under Axial Compression*", (2012).
- [9] Jadhav M. M. & Gunjavate P.V., "*Optimization of Buckling Load for Fiber Composite Laminate by using ANSYS*", International Journal of Advanced Engineering Research and Studies, IJaers/Vol.(n)/IssueI, PP. (144-147), (2012).
- [10] Ali S. & Begum M., "*Numerical Analysis of Slender Partially Encased Composite Columns* ", International Journal of Science and Engineering I, Vol.(1), Issue.(3), PP.(58-65), (2012).
- [11] Anres D. and Julia M., "*Study of Buckling Stress in Steel Alloys*", n.16 Th Asce Engineering 16-17 July, (2003).
- [12] Gabriella T. and Laszlo P. K., "*Buckling of Composite Plates Subjected to Shear and Linearly Varying Loads*", Journal of Materials and Structures, Vol. (4), No. (5), (2007).
- [13] Robert, M. Jones, "*Mechanics of Composite Materials*", Mc Graw-Hill KOGAKUSHA, LTD, Dallas, Texas, USA, (1975).
- [14] Thornton, P.A. & Colangelo, V.J., "*Fundamentals of Engineering Materials*", Prentice –Hall Inc, (1985).
- [15] Hussain, S.A., Pandurangadu K. & palanikuamr K., "*Mechanical Properties of Green Coconut Fiber Reinforced HDPE Polymer Composite*", International Journal of Engineering Science and Technology (IJEST), Vol.3, No.11, PP.(7942-7952), (2011).
- [16] Harring J., "*Statistical Modeling and Regression*", University of Maryland, harring puplic– vitac, PP. (142), (2011).
- [17] Gilberto E. U., "*Regression Analysis with SCILAB*", Info clearing house. com., (2011).
- [18] William D. J. R. Callister, "*Materials Science and Engineering an Introduction*", 5<sup>th</sup> edition, (2000).
- [19] Flex K., Sylvester A. and Edmund A., "*Storage and Handling Techniques of Maize and groundnut* ", SENRA academic publishers, Burnaby, British Columbia, Vol.(6), No.(3), PP.(2122), (2012).
- [20] Standard and Testing Methods (ASTM), "*Standar Test Method for Tensile Properties American of plastic D638M-87b*", Annual book of ASTM standard, Vol. 09.01(1988).
- [21] ANSYS14, Theory Reference Manual, and ANSYS Element Reference, (2009).
- [22] Aslan, Z. and Sahin, M., "*Buckling Behaviour and Compressive Failure of Composite Laminates Containing Multiple Large Delaminations*", Journal of Composite Structures, Elsevier, 89(382-390), (2009).
- [23] Palanivel, R., Mathews, P.K. & Murugan, N., "*Development of Mathematical Model to Predict The Mechanical Properties of Friction Stir Welded AA6351 Aluminum Alloy*", Journal of Engineering Science and Technology Review, 4(1), PP.(25-31), (2011).

Table (1): Mechanical Properties of the Materials used [18].

Material	Density (gm/cm <sup>3</sup> )	Young Modulus (Gpa)	Tensile Strength (Mpa)	Percentage Elongation	Poisson's Ratio
<i>Unsaturated Polyester</i>	1.04-1.46	2.06-4.41	41.4-89.7	< 2.6	0.33
<i>Glass Fiber</i>	2.58	72.5	3450	4.3	0.22

Table (2): The variables of specimen for buckling test.

Type	Angle of Fiber	Volume Fraction	Length (mm)	Width (mm)	Thickness (mm)	Aspect Ratio L/T
<i>Unsaturated Polyester</i>	-	-	140	20	4	3.5
			160			4
			180			4.5
<i>Unsaturated Polyester + Fine Fiber</i>	(0°/90°)	4%	140	20	4	3.5
			160			4
			180			4.5
		7%	140	20	4	3.5
			160			4
			180			4.5
		11%	140	20	4	3.5
			160			4
			180			4.5
	(45°/-45°)	4%	140	20	4	3.5
			160			4
			180			4.5
		7%	140	20	4	3.5
			160			4
			180			4.5
11%		140	20	4	3.5	
		160			4	
		180			4.5	
<i>Unsaturated Polyester + Coarse Fiber</i>	(0°/90°)	3%	140	20	4	3.5
			160			4
			180			4.5
		5%	140	20	4	3.5
			160			4
			180			4.5
		8%	140	20	4	3.5
			160			4
			180			4.5
	(45°/-45°)	3%	140	20	4	3.5
			160			4
			180			4.5
		5%	140	20	4	3.5
			160			4
			180			4.5
8%		140	20	4	3.5	
		160			4	
		180			4.5	



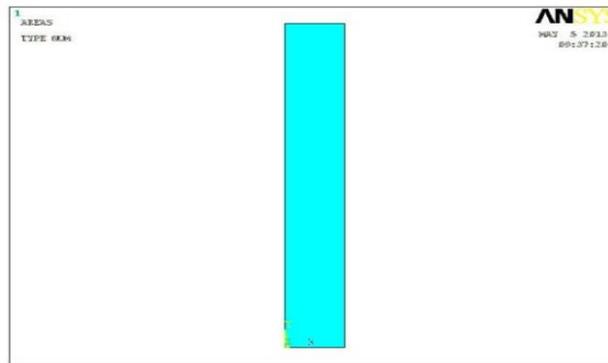


Fig. 4 The geometry of the composite column.

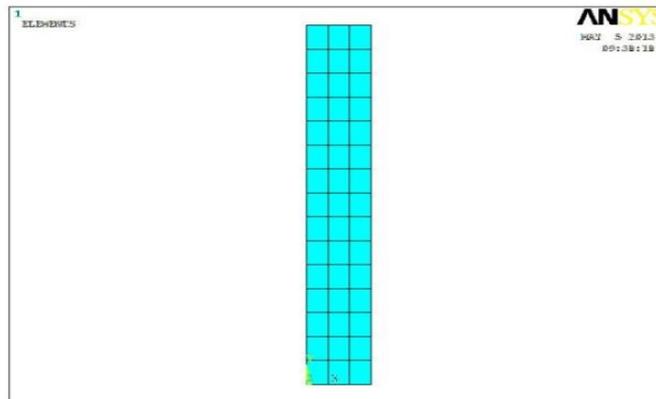


Fig. 5 The mesh of composite column.

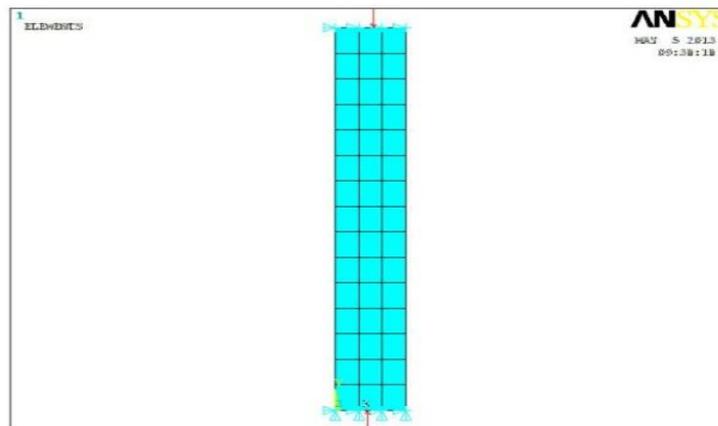


Fig. 6 The applied load on composite column.

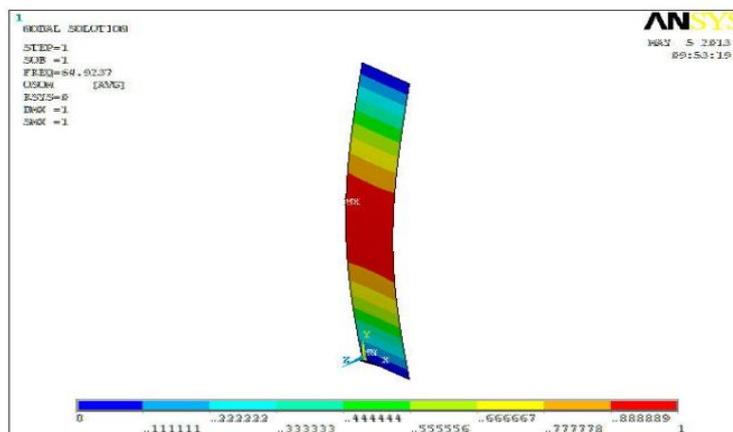


Fig. 7 The first mode of buckling shape of (pin-pin) composite column.

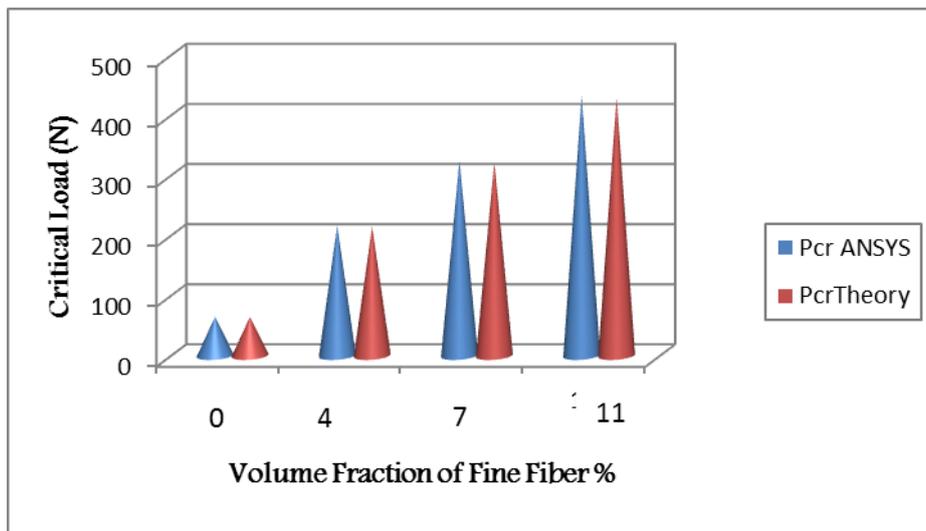


Fig. 8 Volume fraction and critical load for fine fiber at L/T=3.5 &  $\theta = (45^\circ/-45^\circ)$ .

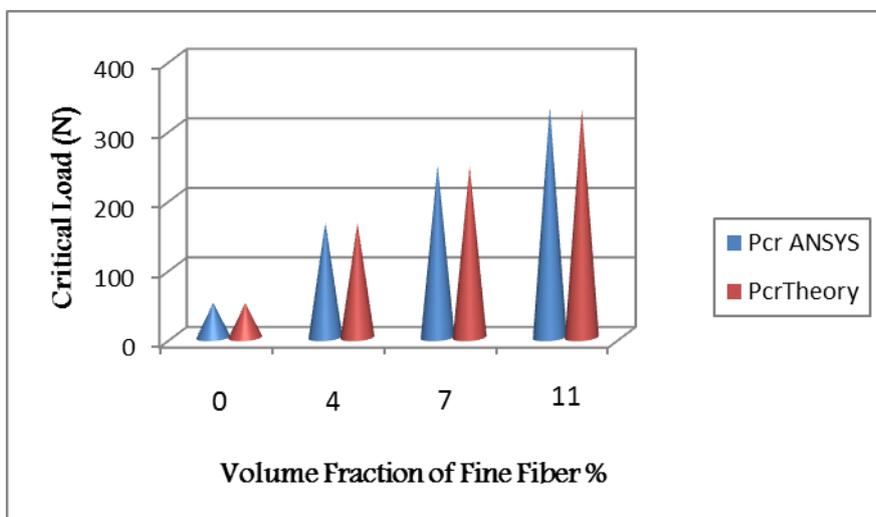


Fig. 9 Volume fraction and critical load for fine fiber at L/T=4 &  $\theta = (45^\circ/-45^\circ)$ .

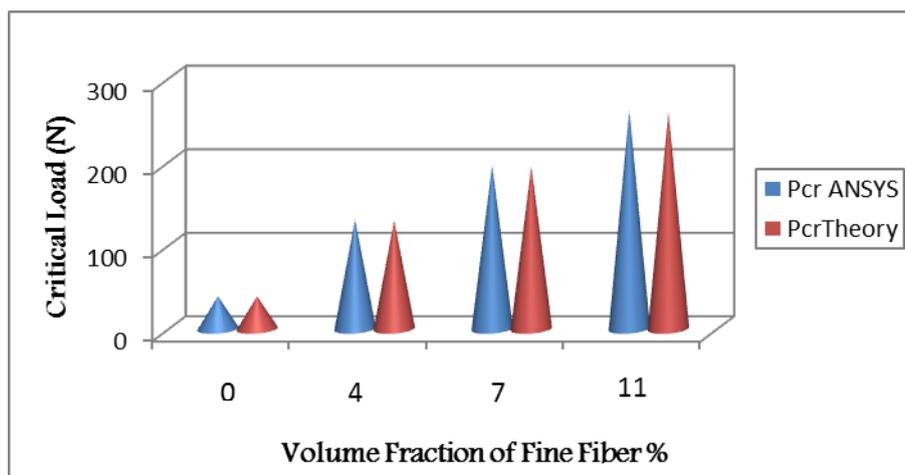


Fig. 10 Volume fraction and critical load for fine fiber at L/T=4.5 &  $\theta = (45^\circ/-45^\circ)$ .

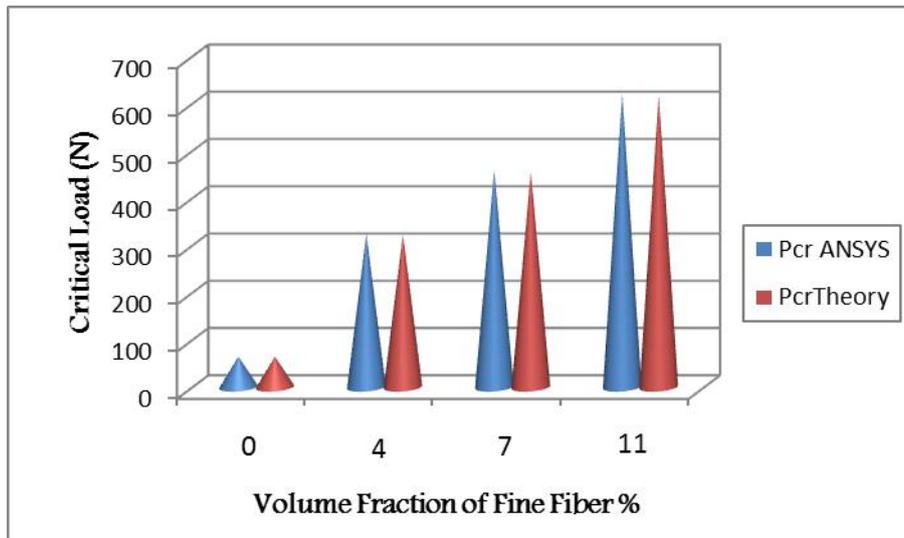


Fig. 11 Volume fraction and critical load for fine fiber at  $L/T=3.5$  &  $\Theta = (0^\circ/90^\circ)$ .

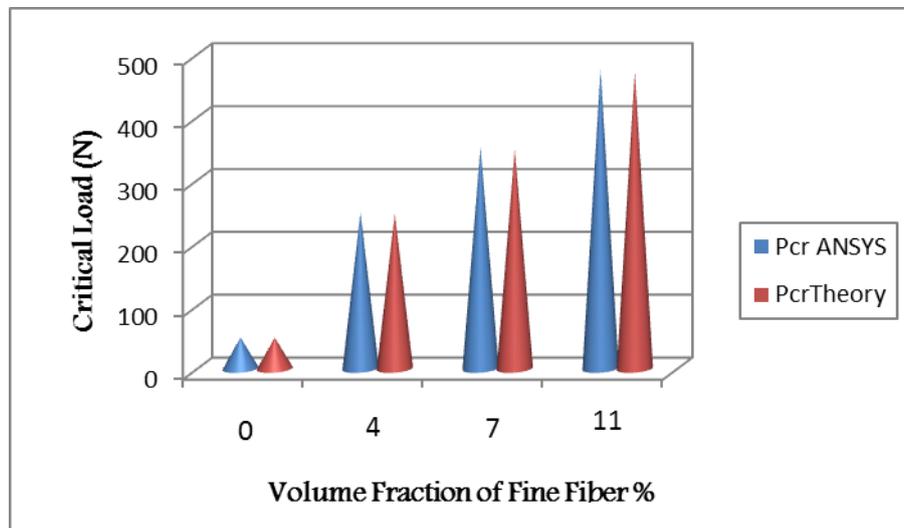


Fig. 12 Volume fraction and critical load for fine fiber at  $L/T=4$  &  $\Theta = (0^\circ/90^\circ)$ .

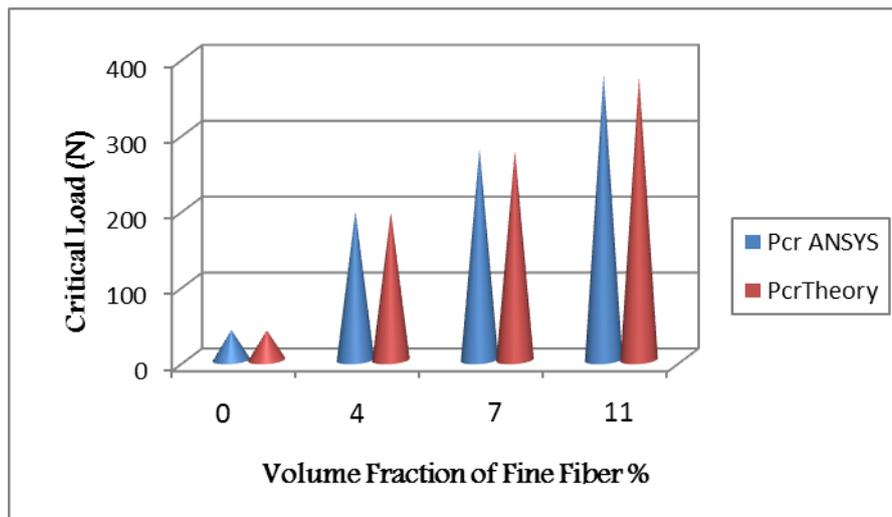


Fig. 13 Volume fraction and critical load for fine fiber at  $L/T=4.5$  &  $\Theta = (0^\circ/90^\circ)$ .

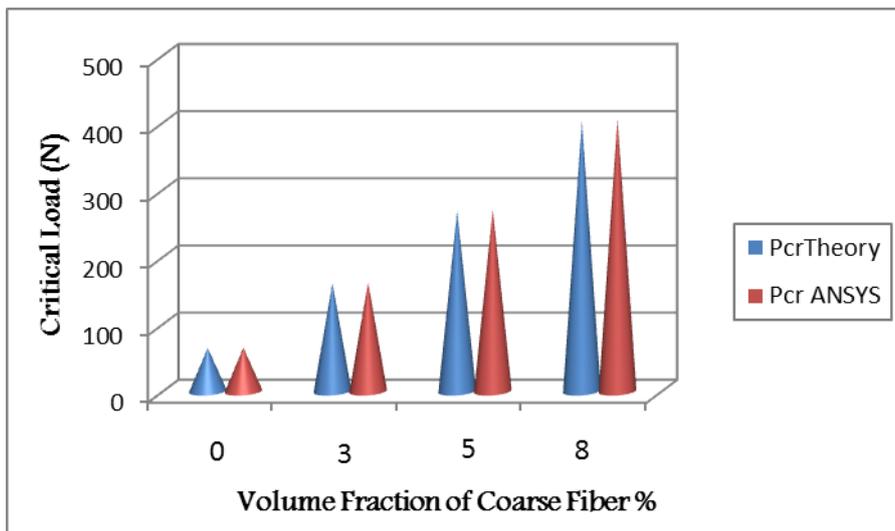


Fig. 14 Volume fraction and critical load for coarse fiber at L/T=3.5 &  $\theta = (45^\circ/-45^\circ)$ .

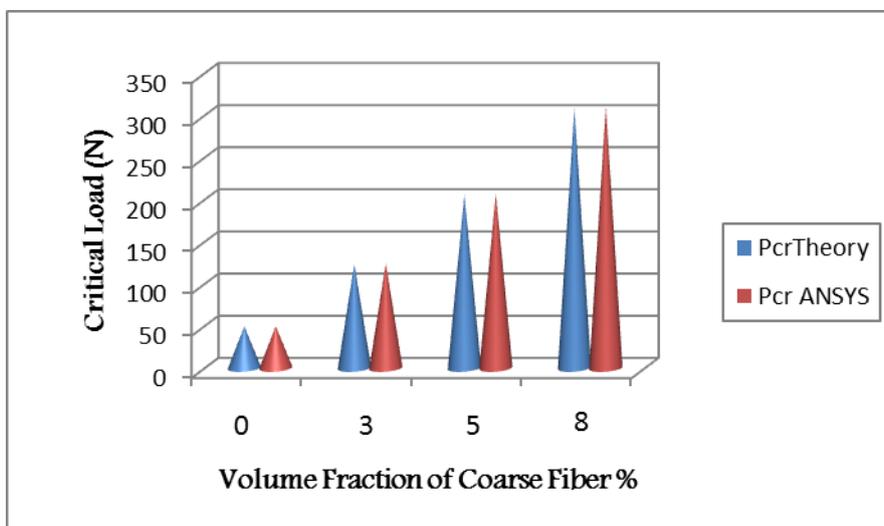


Fig. 15 Volume fraction and critical load for coarse fiber at L/T=4 &  $\theta = (45^\circ/-45^\circ)$ .

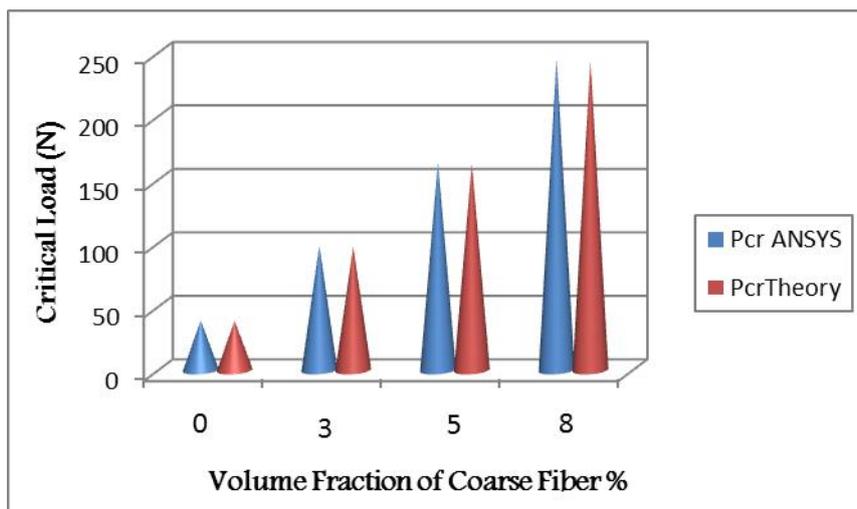


Fig. 16 Volume fraction and critical load for coarse fiber at L/T=4.5 &  $\theta = (45^\circ/-45^\circ)$ .

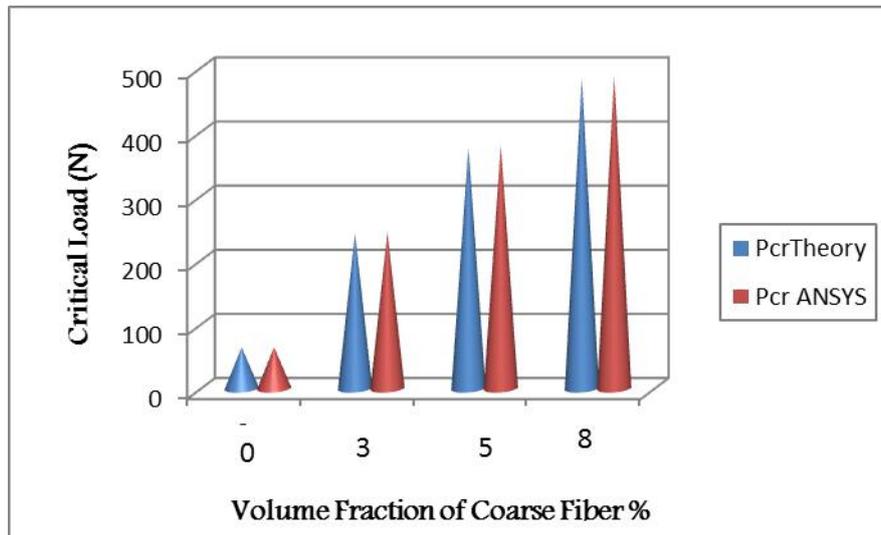


Fig. 17 Volume fraction and critical load for coarse fiber at  $L/T=3.5$  &  $\Theta = (0^\circ/90^\circ)$ .

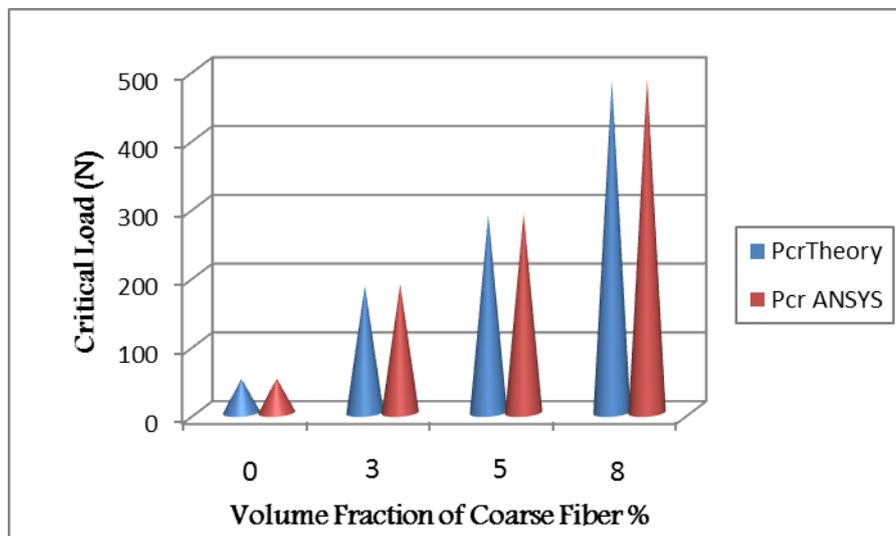


Fig. 18 Volume fraction and critical load for coarse fiber at  $L/T=4$  &  $\Theta = (0^\circ/90^\circ)$ .

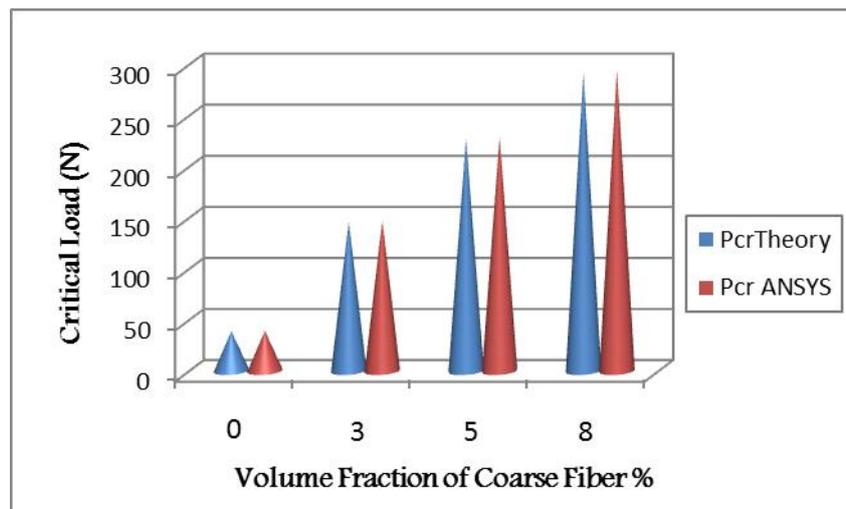


Fig. 19 Volume fraction and critical load for coarse fiber at  $L/T=4.5$  &  $\Theta = (0^\circ/90^\circ)$ .

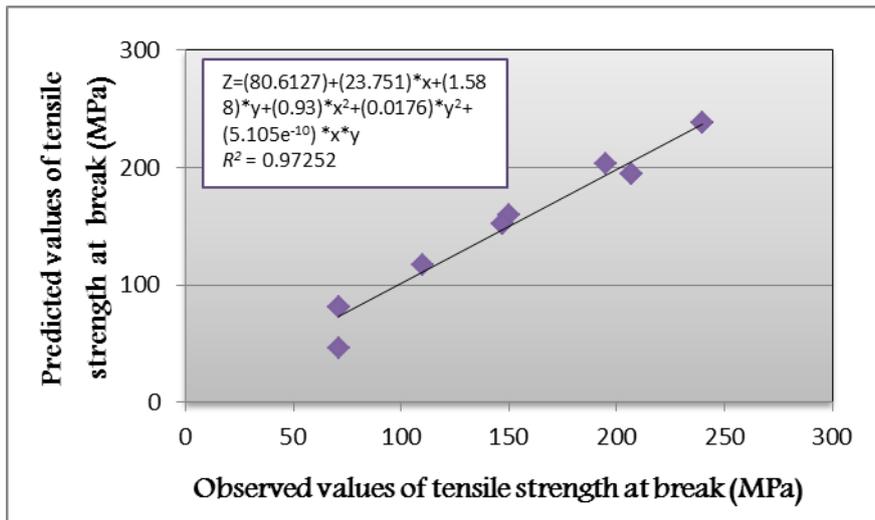


Fig. 20 Scattering diagram of tensile strength at break for fine fiber.

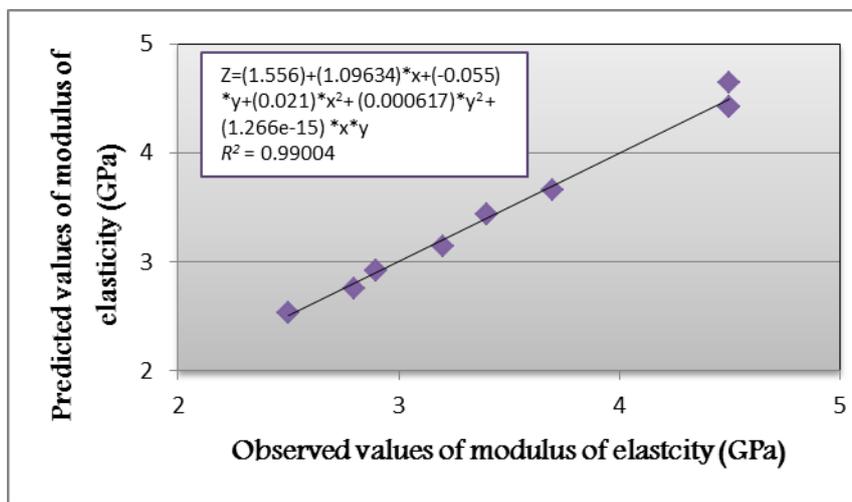


Fig. 21 Scattering diagram of modulus of elasticity for fine fiber.

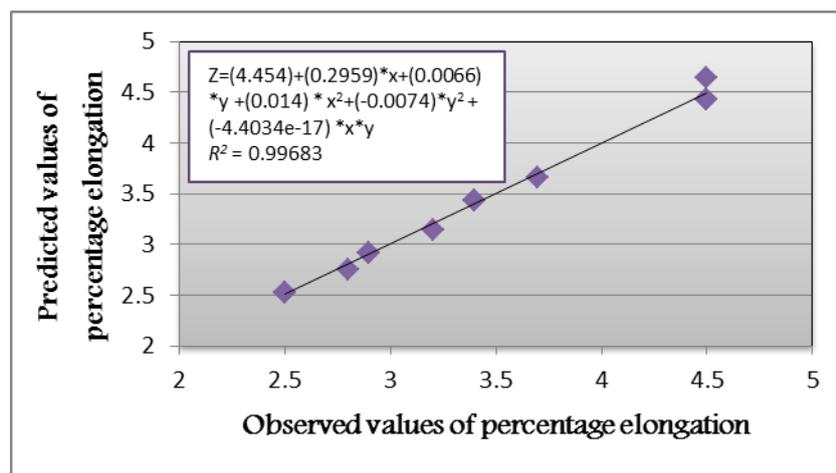


Fig. 22 Scattering diagram of percentage elongation for fine fiber.

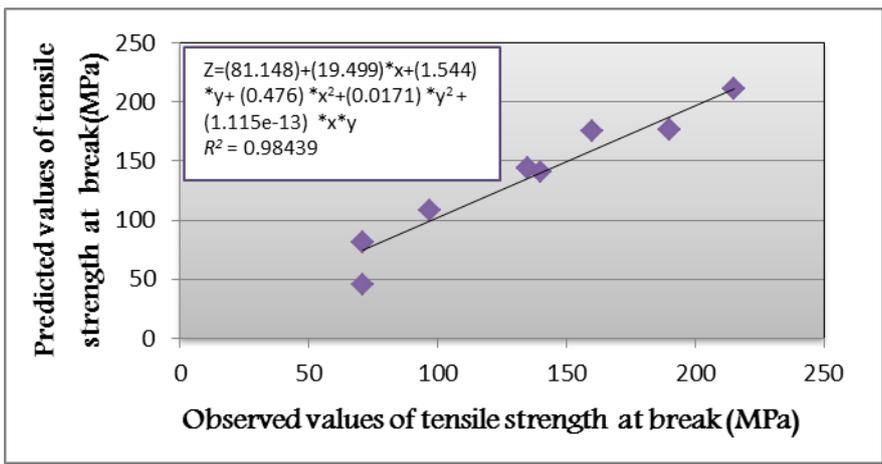


Fig. 23 Scattering diagram of tensile strength at break for coarse fiber.

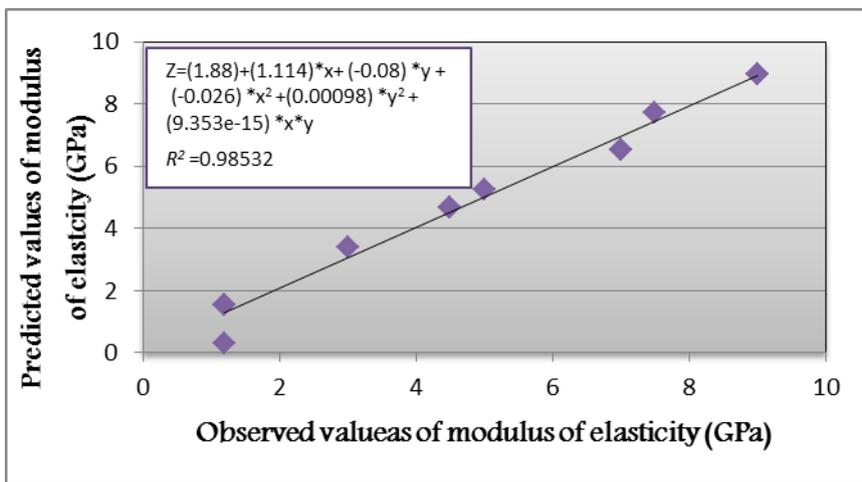


Fig. 24 Scattering diagram of modulus of elasticity for coarse fiber.

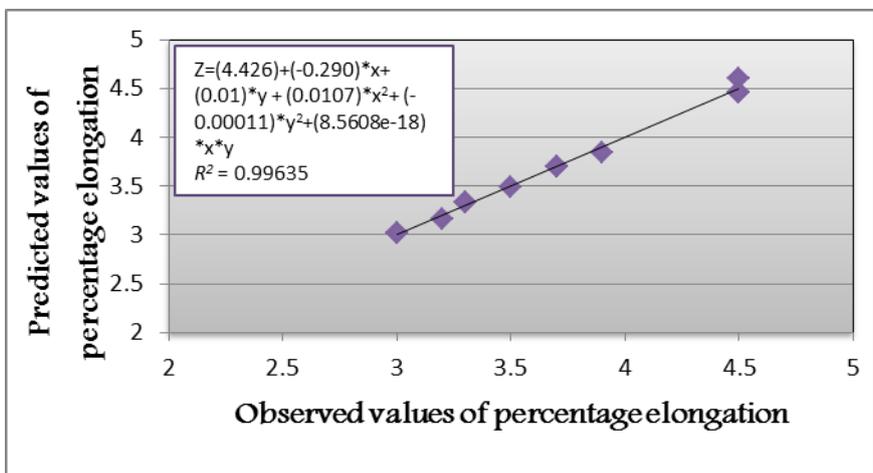


Fig. 25 Scattering diagram of percentage elongation for coarse fiber.