Effect of Variable Fiber Spacing on Buckling Strength of Composite Plates

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Abstract

This paper explores the idea of tailoring the profile of reinforcing fibers to improving buckling strength of composite plates. This paper analyzes the uniaxial buckling behavior of composite laminates with variable fiber spacing using eight node iso parametric finite element methods. The present investigation is limited to single layer composites having parallel fibers. The non uniform spacing fiber results in variable elastic stiffness and non uniform pre buckling stress field, which are shown to have a pronounced influence on the buckling strength. Numerical results are obtained for seven non uniform distributions E-glass fibers in epoxy matrix in rectangular plates with types of boundary condition, and range of aspect ratio. The redistributions are seen to increase the buckling load by as much as 75 % for proposed distribution equation.

Keywords: Buckling behavior, Composite plate, Variable fiber spacing, Finite element method

الخلاصة

هذا البحث يستكشف فكرة صنع ألياف التسليح لتحسين مقاومة الانبعاج للصفائح المركبة. البحث يحلل تصرف الانبعاج المحوري للمركبات المؤلفة من رقائق وذات مسافات بين الألياف متغيرة مستخدما طريقة العناصر المحددة ذات الثمانية عقد. الفحص المقدم محدود لطبقة مركبة واحدة تملك ألياف متوازية. نتائج المسافات الغير منتظمة للألياف تنتج جساءة مرنة متغيرة وإجهادات سابقة للانبعاج غير منتظمة والتي بدورها تعطي تأثير واضح على مقاومة الانبعاج. تم إعطاء نتائج عددية لسبعة معادلات توزيع غير منتظمة لألياف زجاج مغمورة بالايبوكسي لصفيحة مستطيلة الشكل مع أنواع من الإسناد ومدى من نسبة الإبعاد. إعادة التوزيع أظهرت زيادة في حمل الانبعاج بمقدار ٧٥% للمعادلة المقترحة.

الكلمات المفتاحية: السلوك التواء، لوحة المركبة، والمباعدة بين الألياف المتغير، طريقة العناصر المحدودة

1. Introduction

Nowadays, composite laminates have been widely used in modern industry due to their high strength-to-weight ratio, high stiffness-to-weight ratio as well as good fatigue resistant properties. Moreover, the design ability of this kind of material makes it have more development potential than the commonly used metals. Conventional fiber reinforced polymer (FRP) composite laminates are commonly manufactured by bonding many homogeneous single layers which have unified fiber orientation and fiber volume fraction (FVF) together. [Jones,1999]. There are hundreds of published papers dealing with the structural analysis (e.g. static deflections and stresses, vibrations, buckling) of composite plates. Along with this, various laminate theories have been developed, for example, the three-dimensional theories, smeared plate theories, layer-wise models, zigzag models, and global-local models. Very few of them consider plates with variable fiber spacing. If fiber spacing varies, the analysis is considerably more complicated than for uniform spacing. Then the material must be treated as nonhomogeneous on the macroscopic scale, as well as on the microscopic. Governing differential equations then have variable coefficients, instead of constant ones. If initial, in-plane forces are present, the buckling problems require first the solution of the plane elasticity problem to determine the internal stress field. For nonhomogeneous plates the same loading conditions require solutions which are usually more complicated. Moreover, solutions of the subsequent buckling problems are also more complicated [Leissa and Martin,1990]

[Martin and Leissa,1989] investigated the plane stress problem of a rectangular of composite sheet with variable fiber content. The single layer composite having fibers parallel to the edges are macroscopically orthotropic, but nonhomogeneous. The stresses obtained from this analysis were treated as input to the first vibration and buckling study of composites with variable fiber spacing. Numerical results are obtained for six nonuniform distributions of glass, graphite and boron fibers. The redistribution may increase the buckling load by as much as 38%.

[Leissa and Martin,1990] also presented exact solutions for the stress, strain and displacement fields for four types of problems with arbitrary fiber spacing.

[Kue and Shiau,2009] also used a similar concept to reduce the free edge inter laminar stresses. By varying the fiber volume fraction near the free edge, the inter laminar normal and shear stresses near the free edges can be significantly reduced. [Benatta at al,2008] studied stress concentration around holes in composite laminates with variable fiber spacing. [Meftah at all,2008] discussed the effect of different through thickness distribution functions of the FVF on the critical buckling loads and resonance frequencies of the plate by using the FEM. The purpose of them is to design structures with ideal buckling and vibration characteristics via the non-uniform distribution of FVFs. From the preceding review of literature, it is clear that there is no study which considers the buckling analysis of isolated laminated plate under axial compression load by taking into account the variable fiber spacing with sine distribution beside other propositions with type of boundary conditions and aspect ratio effect for single layers. There is also a little amount of literature that takes into eight node element.

2. Formulation of composite laminated plates

Consider a composite laminated plate with length ***a***, width ***b***, and thickness ***h*** as shown in Figure (1). The displacement field with nine degree of freedom per node may be expressed as: [Kaw,2006]

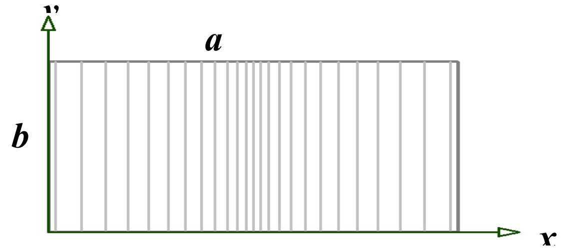


Figure (1): Rectangular composite plate with variable fiber spacing. [Leissa and Martin,1990]

$$\begin{aligned} u(x,y,z) &= u_o(x,y) - z w_{o,x} \\ v(x,y,z) &= v_o(x,y) - z w_{o,y} \qquad (1) \\ w(x,y,z) &= w_o(x,y) \end{aligned}$$

where u_o and v_o are the mid-plane in-plane displacement components of the plate. The kinematic relation can be determined as

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} u_{o,x} \\ v_{o,y} \\ u_{o,y} + v_{o,x} \end{Bmatrix} + z \begin{Bmatrix} -w_{o,xx} \\ -w_{o,yy} \\ -2w_{o,xy} \end{Bmatrix} = \{\varepsilon_o\} + z\{\kappa\} \tag{2}$$

where $\{\varepsilon_o\}$ and $\{\kappa\}$ are the mid-plane strain and plate curvature, respectively.

The plate is assumed to consist of N layers of orthotropic sheets bonded together. Each layer has arbitrary fiber orientation. The fibers in each layer are aligned parallel to the longitudinal direction but distributed unevenly in the transverse direction. Hence, the fiber volume fraction, V_f, is a function of non dimensional coordinate x having its origin at the plate edge of plate as shown in Figure(1). Suppose, for example, the fibers are aligned parallel to the x direction and the fiber volume fraction varies parabolically as $V_f(x) = \left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)$. The material is all fiber at the plate center ($x = a/2$), whereas at the edges ($x = 0, a$), it is all matrix. With this variable fiber spacing, the elastic modulus E_1, E_2, v_{12}, G_{12} for the composite material are also the functions of x. In this study, the formulas used for the calculation of these effective engineering constants are based on the rule of mixture. [Leissa and Martin,1990].

$$\begin{aligned} E_1(x) &= E_f V_f(x) + E_m(1 - V_f(x)) \\ E_2(x) &= \frac{E_f E_m}{E_f(1 - V_f(x)) + E_m V_f(x)} \\ v_{12}(x) &= v_f V_f(x) + v_m(1 - V_f(x)) \\ G_{12}(x) &= \frac{G_f G_m}{G_f(1 - V_f(x)) + G_m V_f(x)} \end{aligned} \tag{4}$$

The stress–strain relation for the orthotropic sheet with variable fiber spacing can be expressed as:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix}^L = \begin{bmatrix} Q_{11}(x) & Q_{12}(x) & 0 \\ Q_{12}(x) & Q_{22}(x) & 0 \\ 0 & 0 & Q_{66}(x) \end{bmatrix} \left\{ \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} \right\} \tag{5}$$

Where:

$$\begin{aligned} Q_{11}(x) &= \frac{E_1(x)}{(1 - v_{12}(x) v_{21}(x))} \\ Q_{12}(x) &= \frac{v_{12}(x) E_1(x)}{(1 - v_{12}(x) v_{21}(x))} \\ Q_{22}(x) &= \frac{E_2(x)}{(1 - v_{12}(x) v_{21}(x))} \\ Q_{66}(x) &= G_{12}(x) \end{aligned} \tag{6}$$

For a composite laminated plate with N layers, the stress–strain relation of kth layer of the plate can be expressed as:

$$\{\sigma\}_k = [Q]_k \{\varepsilon\} \tag{7}$$

where Q_{ij} are the transformed reduced stiffness. Now the stress–strain relation becomes location dependent. The force and moment resultants of the composite laminated plate are defined as: [Kuo and Shiau,2009]

$$[N] = [N_x \quad N_y \quad N_{xy}]^L = \int_{-h/2}^{h/2} [\sigma_x \quad \sigma_y \quad \tau_{xy}] dz \tag{8}$$

$$[M] = [M_x \quad M_y \quad M_{xy}]^L = \int_{-h/2}^{h/2} [\sigma_x \quad \sigma_y \quad \tau_{xy}] z dz \tag{9}$$

Which leads to,

$$\begin{aligned} \{N\} &= [A]\{\varepsilon_o\} \\ \{M\} &= [D]\{\kappa\} \end{aligned} \tag{10}$$

Where the extensional rigidity [A] and bending rigidity [D] of the panel are defined as:

$$A_{ij} = \sum_{k=1}^{N} Q_{ij}(h_k - h_{k-1}) \qquad i, j = 1, 2, 6 \tag{11 a}$$

$$D_{ij} = \frac{1}{3}\sum_{k=1}^{N} Q_{ij}(h_k^3 - h_{k-1}^3) \qquad i, j = 1, 2, 6 \tag{11 b}$$

The total potential energy Π of a deformed plate is defined as

$$\Pi = U - W \tag{12}$$

where U is the potential energy of deformation (strain energy) and W is the potential energy of the external loading.

The state of equilibrium of a deformed plate can be characterized as that for which the first variation of the total potential energy of the system is equal to zero.

$$d\Pi = dU - dW = 0 \tag{13}$$

or

$$dU = dW \tag{14}$$

The components of the Piola-Kirchhoff stress vector, thus

$$dU = \int_V d\bar{\varepsilon}^T \sigma \, dV = \int_A \int_{-\frac{h}{2}}^{\frac{h}{2}} (d\varepsilon_x \sigma_x + d\varepsilon_y \sigma_y + d\gamma_{xy}\tau_{xy} + d\gamma_{xz}\tau_{xz} + d\gamma_{yz}\tau_{yz}) \, dz \, dA \tag{15}$$

And can be rewritten the above equation as

$$dU = \int_A d\bar{\varepsilon}^T \sigma \, dA \tag{16}$$

The work done by the in-plane forces, N_x and N_y, in the x and y directions can be expressed as:

$$dW = \int N_x u_o \, dy + \int N_y v_o \, dy + \frac{1}{2}\int \left(N_x (w_{o,x})^2 + N_y (w_{o,y})^2\right) dA \tag{17}$$

Substituting Equations (15) and (17) into Equation (13) can give the equilibrium equations written as:

$$\Psi(u) = \int_V [B]^T \sigma \, dV - dW = 0 \qquad \textbf{(18)}$$

Where, Ψ represents the sum of external and internal generalized forces and by taking appropriate variation of Equation (18) with respect to ***du***:

$$d\Psi = \int_V d[B]^T \bar{\sigma} \, dV + \int_V [B]^T d\bar{\sigma} \, dV \qquad \textbf{(19)}$$

Where [B] is the strain-displacement matrix, thus

$$\int_V [B]^T d\bar{\sigma} \, dV = \int_A [B]^T [D][B] dA = [K_o] \qquad \textbf{20)}$$

where $[K_o]$ is the standard or linear stiffness matrix. From the first term of Equation (19) can be written as:

$$\int_V d[B_L]^T \bar{\sigma} \, dV = [K_\sigma] \qquad \textbf{(21)}$$

where $[K_\sigma]$ is a symmetric matrix dependent on the stress level. This matrix is known as initial stress matrix or geometric matrix. So, In the present study the selective integration rule has been adopted to compute the integration of the matrices where (3×3) is used for bending and membrane energies and (2×2) for transverse shear energies. The final form of tangent stiffness such as:

$$[K_T] = [K_o] + \lambda [K_\sigma] \qquad \textbf{(22)}$$

The term **λ** in the above equation is the load factor that amplifies this initial stress field. As a consequence of equation (4.45), the buckling criterion becomes:

$$\boldsymbol{Det}\left([K_o] + \lambda [K_\sigma]\right) = 0 \qquad \textbf{(23)}$$

which is an eigenvalue problem, and by solving the problem, the critical buckling load P_{cr} may be found from the lowest eigenvalue of the system. In the present study was used eight-node Serendipity element shown in Figure (3). This element contains four nodes at the corners, four nodes at the mid-sides of the element boundaries. The topology order is counter-clockwise in the sequence from 1 to 8 .[Bathe,1996].

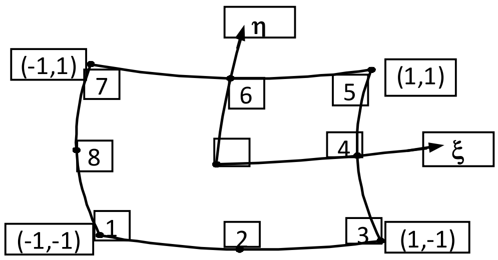


Figure (3): Eight-node quadrilateral iso parametric element. [Bathe,1996]

3. Numerical results

In order to study the effect of variable fiber spacing, boundary conditions, and aspect ratios, on the buckling strength of a rectangular composite plate, several plates are analyzed. The correctness of the buckling analysis is first checked with the case studied by [Leissa and Martin,1990] and with [Kuo and Shiau,2009].

Table(1) shows the non dimensional critical buckling stresses $\bar{\sigma}_{cr} = \frac{L^2}{E_f h^2}\sigma_{cr}$ for glass epoxy composite plates with six different fiber distributions (V_f). The material properties of the analyzed plate are (E_f=73.1 GPa, E_m= 3.44 GPa,G_f= 29.67 GPa, G_m= 1.277 GPa, ν_f=0.22, ν_m=0.35, a=b=1.0 m, h=0.01 m). The critical buckling stresses are compared to Leissa and Martin's study and to Kuo and Shiau's study. The critical buckling stresses for the fiber distributions 3 and 6 not compared to Leissa and Martin's study due to the miscalculation for the fiber volume fraction Vfav in the former study.

For the present study, it is seen that the maximum difference is 6.0% for the fiber distribution 1 according to [Leissa and Martin,1990] study and maximum difference is 3.5% for the fiber distribution 1 according to Leissa and Martin study.

[Kuo and Shiau,2009] proposed new formula for distribution of fiber such as $V_f(x) = V_{fout} + (V_{fin} - V_{fout})\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^n$ where V_{fin} is the fiber volume fraction at the plate center (x = $L/2$) and V_{fout} is the fiber volume fraction at the edges (x = $0, L$). The volume fraction index n controls the variation of the volume fraction. The new fiber distribution includes the previous six fiber distributions.

Figure(4) shows the comparison of the present study with Kou and Shiau study for the critical buckling stresses with V_{fin} for glass epoxy composites with fiber distribution $V_f(x) = V_{fout} + (V_{fin} - V_{fout})\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^n$.

It can be noticed that the critical buckling load may be increased by increasing the fiber volume fraction. The more fibers distributed in the central portion of the plate may efficiently increase the critical buckling load by use of the same fiber volume fraction V_{fav}. Besides, the fibers distributed in the outer portion of the plate may also increase the critical buckling load.

Table (1): Comparison of critical buckling stresses for non-homogeneous glass epoxy composites

No.	$V_f(x)$	$\bar{\sigma}_{cr} = \frac{L^2}{E_f h^2}\sigma_{cr}$		
		Leissa and Martin	Kuo and Shiau	Present study
1	$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)$	1.0859	1.1111	1.1500
2	$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^2$	0.8451	0.8798	0.900
3	$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^3$	-	0.7675	0.7560
4	$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)$	0.9346	0.9334	0.9380
5	$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)^2$	0.8897	0.8882	0.8930
6	$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)^3$	-	0.8607	0.8650

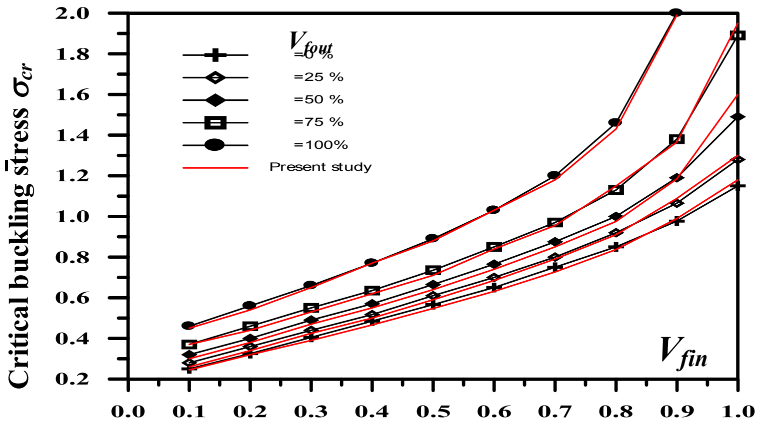


Figure (4): Critical buckling stresses for square glass epoxy composites with different outer fiber volume fraction

New form of distribution fiber spacing was proposed by the present study to improve the buckling strength of composite plate which using sine wave distribution equation as $V_f(x) = \left|\sin\left(\frac{n\pi x}{L}\right)\right|$ where ***n*** is the waviness number. Table (2) and Figure 5 show the effect of waviness number on the non dimensional critical buckling load of composite plated used in the previous case. From this study it can be noticed that the n=4 gives high strength of buckling and thus will used in the post study.

Table(2): Comparison of waviness number for critical buckling stresses of composite plate

$V_f(x)$	$\bar{\sigma}_{cr} = \frac{L^2}{E_f h^2}\sigma_{cr}$							
	n=1	***n***=2	***n***=3	***n***=4	***n***=5	***n***=6	***n***=7	***n***=8
$\left\lvert\sin\left(\frac{n\pi x}{L}\right)\right\rvert$	1.255	1.117	1.106	1.752	1.139	0.975	1.183	0.567

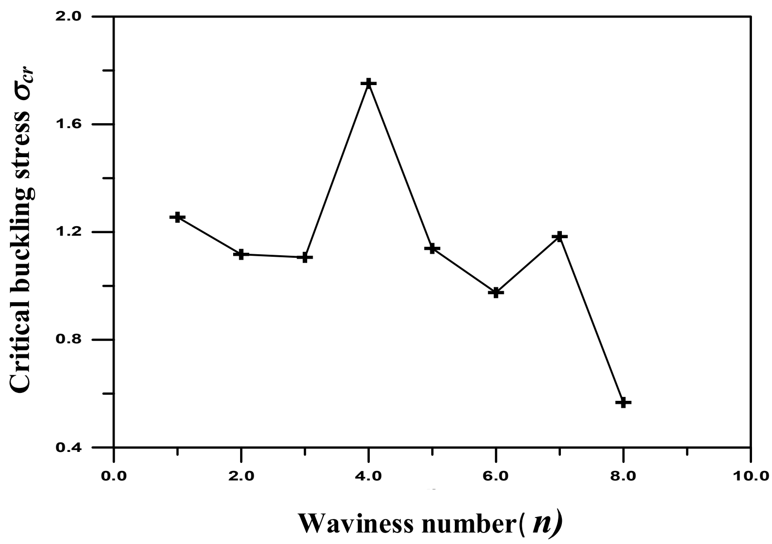


Figure (5): waviness number for critical buckling stresses of composite plate

Table (3) shows the comparison between the composite plate with constant spacing fiber and with composite plate with variable fiber spacing for the same value of volume fraction using seven equations of distribution. From this table can be noticed that the composite plate with variable fiber spacing gives buckling strength greater than the composite plate with constant fiber spacing and so the proposed equation of distribution gives high buckling strength compared with other equations of distribution fiber. The proposed equation gives increasing about 52.3% in the critical buckling strength compared with the highest other distribution equation.

Table (3):Comparison of critical buckling stresses for Composite plate with variable spacing fiber and constant fiber spacing

$V_f(x)$	**Volume fraction of fiber (%)**		$\bar{\sigma}_{cr}=\dfrac{L^2}{E_f h^2}\sigma_{cr}$	
	V_{fmax}	V_{fav}	**Variable spacing fiber**	**Constant spacing fiber**
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)$	**100**	**66.67**	**1.150**	**0.896**
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)^2$	**100**	**53.34**	**0.900**	**0.713**
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)^3$	**100**	**45.70**	**0.756**	**0.617**
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)$	**75**	**66.67**	**0.938**	**0.896**
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)^2$	**75**	**63.34**	**0.893**	**0.849**
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)^3$	**75**	**61.42**	**0.865**	**0.821**
$\left\|\sin\left(\frac{4\pi x}{L}\right)\right\|$	**100**	**63.67**	**1.752**	**0.850**

The effect of boundary condition on the buckling strength of composite plate with variable and constant fiber spacing was studied in Table (4). Table(4) shows the non dimensional critical buckling stresses for glass epoxy composite plates with seven different fiber distributions (***V_f***) and constant fiber distribution. The material properties of the analyzed plate are (***E_f***=73.1 GPa, ***E_m***= 3.44 GPa,***G_f***= 29.67 GPa, ***G_m***= 1.277 GPa, ***v_f***=0.22, ***v_m***=0.35, ***a***=***b***=1.0 m, ***h***=0.01 m). from this table, it can be noticed that the type of boundary condition effects on the buckling strength of composite plate and besides to this the buckling strength of composite plate with variable fiber spacing much more the composite plate with constant fiber spacing fro all types of boundary conditions.

Table(4):Critical buckling stresses of Composite plate with variable spacing fiber with types of boundary conditions

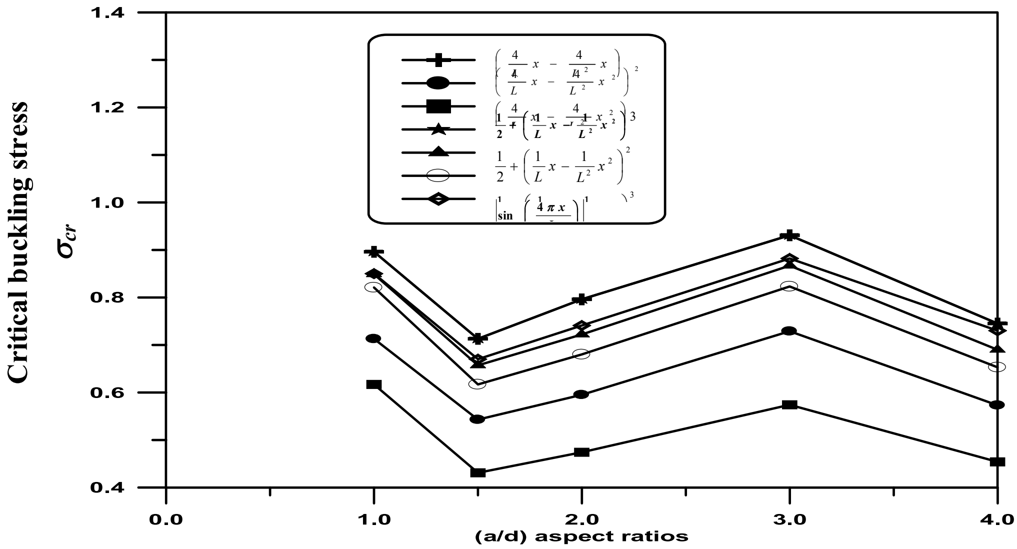
$V_f(x)$	$\bar{\sigma}_{cr} = \frac{L^2}{E_f h^2}\sigma_{cr}$					
	All edge simply (SSSS)		**All edge clamped (CCCC)**		**Two ends simply and other clamped (CSCS)**	
	V.S.F.	**C.S.F.**	**V.S.F.**	**C.S.F.**	**V.S.F.**	**C.S.F.**
$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)$	**1.150**	**0.896**	**4.284**	**2.997**	**2.790**	**1.402**
$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^2$	**0.900**	**0.713**	**3.169**	**2.408**	**1.860**	**1.090**
$\left(\frac{4}{L}x - \frac{4}{L^2}x^2\right)^3$	**0.756**	**0.617**	**2.790**	**2.085**	**1.410**	**0.944**
$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)$	**0.938**	**0.896**	**3.042**	**2.997**	**1.511**	**1.402**
$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)^2$	**0.893**	**0.849**	**2.919**	**2.851**	**1.432**	**1.316**
$\frac{1}{2} + \left(\frac{1}{L}x - \frac{1}{L^2}x^2\right)^3$	**0.865**	**0.821**	**2.860**	**2.757**	**1.383**	**1.267**
$\left\lvert \sin\left(\frac{4\pi x}{L}\right)\right\rvert$	**1.752**	**0.850**	**4.445**	**2.859**	**3.628**	**1.318**

The effect of aspect ratio on the buckling strength of composite plate with variable and constant fiber spacing was studied in table (5). The range of aspect ratio (1,1.5,2,3, and 4) was respect in the present study.

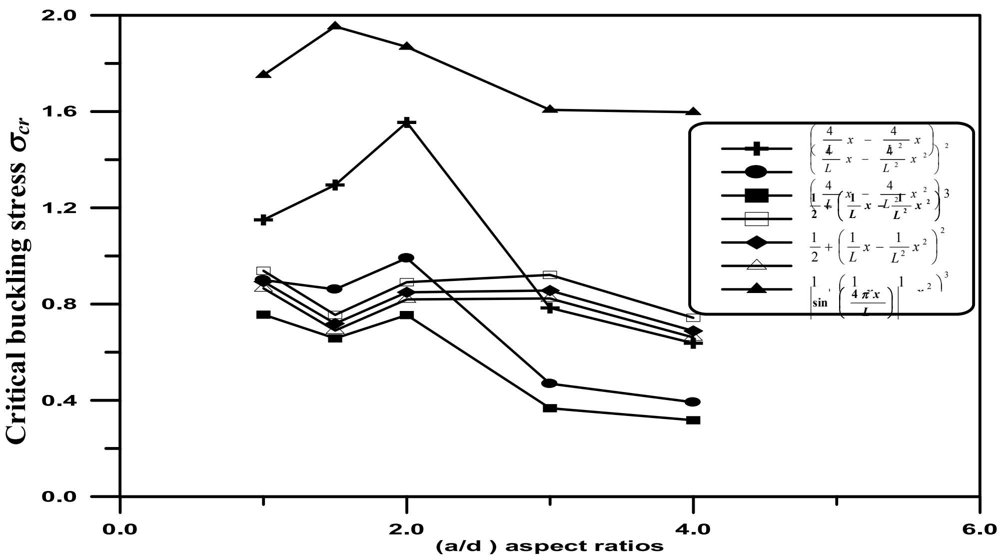
Table (5) and Figures 6 and 7 shows the non-dimensional critical buckling stress of composite plate with variable and constant fiber spacing. From this can be noticed that the buckling strength of composite plate with variable fiber spacing less than the buckling strength of composite plate with constant fiber spacing when the aspect ratio about equal and greater than 3 for all equations of distribution except the proposed equation gives buckling strength greater than the constant fiber for all range of aspect ratio.

Table(5):Critical buckling stresses of Composite plate with variable spacing fiber with range of aspect ratios

$V_f(x)$	$\overline{\sigma}_{cr}=\frac{L^2}{E_f h^2}\sigma_{cr}$									
	a/*b*=1		*a*/*b*=1.5		*a*/*b*=2.0		*a*/*b*=3.0		*a*/*b*=4.0	
	V.S.F.	C.S.F.	V.S.F.	C.S.F.	V.S.F.	C.S.F.	V.S.F.	C.S.F.	V.S.F.	C.S.F.
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)$	1.150	0.896	1.295	0.713	1.555	0.796	0.784	0.931	0.637	0.745
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)^2$	0.900	0.713	0.861	0.543	0.991	0.595	0.469	0.729	0.392	0.573
$\left(\frac{4}{L}x-\frac{4}{L^2}x^2\right)^3$	0.756	0.617	0.657	0.431	0.754	0.474	0.367	0.574	0.317	0.454
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)$	0.938	0.896	0.755	0.713	0.891	0.796	0.921	0.931	0.743	0.745
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)^2$	0.893	0.849	0.719	0.657	0.849	0.722	0.856	0.867	0.688	0.690
$\frac{1}{2}+\left(\frac{1}{L}x-\frac{1}{L^2}x^2\right)^3$	0.865	0.821	0.690	0.617	0.819	0.680	0.823	0.823	0.661	0.653
$\left\|\sin\left(\frac{4\pi x}{L}\right)\right\|$	1.752	0.850	1.954	0.67	1.869	0.741	1.607	0.882	1.597	0.730



Figure(6): Critical buckling stresses of Composite plate with Constant spacing fiber with range of aspect ratios



Figure(7):Critical buckling stresses of Composite plate with variable spacing fiber with range of aspect ratios

3.Conclusions

Buckling strength of composite laminated plates with variable and constant fiber spacing was studied using finite element method. Eight node isoparametric elements with five degree of freedom per node were used in the present study. From the present results, the following conclusions can be drawn:

1- The buckling strength of composite plate with variable and constant fiber spacing may be increased by increasing the fiber volume fraction.
2- The more fibers distributed in the central portion of the composite plate may efficiently increase the buckling load
3- The fibers distributed in the outer portion of the plate may increase the buckling strength of composite plate.
4- The buckling strength of composite plate with variable spacing fiber affect by aspect ratio where becomes less than the buckling strength of composite with constant fiber spacing when the aspect ratio equal to and greater than 3 for all equations of distribution fibers except the proposed sine wave equation.
5- A sine wave distribution fiber gives more efficient equation from other equation to improve the buckling strength of composite plate.

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