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# Experimental and Finite Element Studies on Buckling of Laminated E-Glass Woven Fabric Epoxy Composite Plates

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***Abstract*— The laminated composite structures have wide application in aerospace, mechanical, civil and other areas of engineering chiefly due to the low value of specific weight and high values of specific strength and specific stiffness. The thickness of members and structures made of composite materials is usually very small and hence prone to buckling. Buckling behavior of laminated composite plates subjected to in-plane loads is an important consideration in the preliminary design of automobile components. Composite plates with circular holes and other openings are extensively used as structural members in automobile design and other fields. In this work, experimental and finite element studies are made on buckling of rectangular plates made of laminated E-glass woven fabric epoxy composite plates with and without cutouts. The effects of (i) fabric orientation angle and (ii) shape of cutout (circular, square and rectangular) on the critical buckling load are determined. It is observed that for all composite plates considered here, the value of critical buckling stress given by FEM (finite element method) is higher than the corresponding experimental value, the discrepancy varying from small to moderate. The critical buckling stresses given by both experimental and finite element methods decrease monotonically as the fabric orientation angle increases. The values are maximum for $0^0$ fabric orientation and minimum for $45^0$ fabric orientation. The values of the critical buckling load given by buckling experiment and FEM reduce when cutouts/holes are introduced in the composite plates. The reduction in the value of critical buckling load is considerable. The shape of the hole does influence, although not significantly, the critical buckling load when the areas of the holes are almost same. The plate with circular hole yields higher value when compared with a plate with square/rectangular hole.**

***Keywords*— laminated composite plate; woven fabric; fabric orientation; cutout; critical buckling load; finite element analysis***

## I. INTRODUCTION

Fiber-reinforced and fabric reinforced composites are used extensively in the form of thin plates which are prone to buckling. Hence an understanding and evaluation of their buckling behavior is vital in the safe and reliable design of laminated composite plates. There are several analytical and numerical studies made on thin laminated composite plates and a few of them are briefly mentioned here. Shukla and Kreuzer [1] proposed a formulation based on the first-order shear deformation theory and von-Karman-type nonlinearity to estimate the critical buckling load of laminated composite rectangular plates under in-plane uniaxial and biaxial loadings. Different combinations of simply supported, clamped and free boundary conditions were considered. The effects of plate aspect ratio, lamination scheme, number of layers and material properties on the critical loads were studied. Chainarin Pannok et al. [2] studied the buckling behavior of rectangular and skew thin composite plates with various boundary conditions using the Ritz method along with the proposed out-of-plane displacement functions. Buket Okutan Baba [3] conducted numerical and experimental studies and investigated the effect of boundary conditions, length/thickness ratio and ply orientation on the buckling behavior of E-glass/epoxy composite rectangular plates with and without cutouts under in-plane compression load. Pein and Zahari [4] studied the structural behavior of woven fabric composites with and without holes subject to compressive load. Murat Yazici [5] studied the influence of square cut-out on the buckling stability of multilayered, steel woven fiber-reinforced polypropylene thermoplastic matrix composite plates using numerical and experimental methods. Ganesan C and P K Dash [6] studied the effect of holes in plate elements on the stability. This study dealt with the buckling analysis of symmetrically laminated composite plates with two sides simply supported and the remaining two sides free. Priyanka

Dhurvey and N D Mittal [7] have studied buckling behavior of an orthotropic composite laminate using finite element analysis. It was seen that the presence of cutout reduces the buckling load due to stress concentration and material removal effect and the stress concentration effect is more important than the material removal effect provided that the dimension of cutout is not so large with respect to the plate dimension.

The present work deals with linear buckling analysis of laminated E-glass woven fabric epoxy rectangular composite plates with two opposite edges simply supported and the remaining edges free. The effects of fabric orientation, shape of cutout on the critical buckling load of plates are experimentally and numerically investigated here.

## II. MATERIALS AND METHODOLOGY

The methodologies used in the present work are (i) buckling experiment using Universal Testing Machine (UTM) and (ii) classical/linear buckling analysis using finite element software ANSYS.

### *A. Properties of composite plates used*

The properties of woven E-glass and Epoxy used in the present work were supplied by vendors and the same are presented in Table 1.

TABLE 1: PROPERTIES OF WOVEN E-GLASS AND EPOXY

| **Property** | **E-glass** | **Epoxy (Araldite-LY556)** |
|---|---|---|
| Volume fraction in % | 65 | 35 |
| Young's modulus in GPa | 73 | 3.4 |
| Poisson's ratio | 0.20 | 0.35 |
| Density in g/cc | 2.5 | 1.2 |
| Shear modulus in GPa | 30 | 1.49 |

Number of layers = 10; Longitudinal Young's Modulus = 48.64 GPa ; Transverse Young's Modulus = 8.94 GPa; Major Poisson's Ratio = 0.25; Minor Poisson's Ratio = 0.046; Rigidity Modulus = 3.89 GPa.

### *B. Preparation of test specimens*

A plastic sheet was kept on a flat granite table and a thin film of polyvinyl alcohol was applied as a releasing agent using spray gun. A gel coat (epoxy and hardener) was applied to the mould by brush to provide a smooth external surface and to protect the fabric from direct exposure to the environment. A layer of woven fabric (see Fig.1) was placed on the mould at the top of the gel coat and the gel coat was applied by brush.

Fig. 1: Woven E-glass Fabric.

Any air which may be entrapped was removed using serrated steel rollers. This process was repeated for the remaining layers of woven fabric. A total of 10 layers of woven fabric were used. Again, a plastic sheet was placed at the top of plate by applying polyvinyl alcohol inside the sheet as releasing agent. Then curing of the plates was done at atmospheric pressure. The plates were left for a minimum of 6 to 8 hours before being transported and cut to exact shape for testing. Later, the plates were post-cured at $100^0$ C in oven for 2 hours. The materials were used for fabricating the plates are (i) Epoxy as resin, (ii) Hardener (Araldite LY556) as catalyst, (iii) E-glass Woven Fabric as reinforcement and (iv) Polyvinyl alcohol as a releasing agent. Each layer had one E-glass woven fabric oriented in the same direction. The various fabric orientations used in this work are $0^o$, $30^o$ and $45^o$. Circular, square and rectangular cutouts were made in the composite plates at the centre. The details of the composite plate specimens used in the present study are given in Table 2.

TABLE 2: DETAILS OF LAMINATED COMPOSITE PLATES USED

| **Orientation of fabric** | **No. of identical plates cast** | **Cutout details** | **Length (mm)** | **Width (mm)** | **Thickness (mm)** |
|---|---|---|---|---|---|
| $O^0$ | 3 | No cutout | 130 | 120 | 3 |
| $30^0$ | 3 | No cutout | 130 | 120 | 3 |
| $45^0$ | 3 | No cutout | 130 | 120 | 3 |

| | | | | | |
|---|---|---|---|---|---|
| $O^0$ | 3 | Circular cutout of 40 mm dia. | 130 | 120 | 3 |
| $30^0$ | 3 | Circular cutout of 40 mm dia. | 130 | 120 | 3 |
| $45^0$ | 3 | Circular cutout of 40 mm dia. | 130 | 120 | 3 |
| $O^0$ | 3 | Square cutout of 35 mm side | 130 | 120 | 3 |
| $30^0$ | 3 | Square cutout of 35 mm side | 130 | 120 | 3 |
| $45^0$ | 3 | Square cutout of 35 mm side | 130 | 120 | 3 |
| $O^0$ | 3 | Rectangular cutout of 30 x 40 mm size | 130 | 120 | 3 |
| $30^0$ | 3 | Rectangular cutout of 30 x 40 mm size | 130 | 120 | 3 |
| $45^0$ | 3 | Rectangular cutout of 30 x 40 mm size | 130 | 120 | 3 |

### *C. Buckling experiment*

The prepared test specimen was placed in the uniaxial tensile testing machine and loaded axially in compression. The shape of a typical composite plate after buckling is shown in Fig.2. The out-of-plane displacement at midspan of the plate was measured by dial guages. A plot of applied load versus midspan deflection was made and the experimental value of the critical buckling load was determined.

**Fig.2: Shape of laminated composite plate after buckling**

### *D. Finite element analysis*

ANSYS was used to carry out the finite element buckling analysis of composite plates. 3D 4-node SHELL 181 element of ANSYS library was used to compute the critical buckling load of composite plates. A finite element mesh of size 24 x 26 was selected after making convergence study for the computation of critical buckling stress.



## III. RESULTS AND DISCUSSION

### *A. Experimental and FEM results*

The critical buckling stress is obtained by dividing the critical buckling load by the cross-sectional area (width x thickness). For each case, the average of three experimental determinations was adopted. The average value of critical buckling stress obtained from experiments and the corresponding value given by finite element analysis are presented in Table 3.

TABLE 3: VALUES OF CRITICAL BUCKLING STRESS FOR VARIOUS PLATES

| **Orientation of fabric** | **Cutout details** | **Critical buckling stress in MPa** | | |
|---|---|---|---|---|
| | | ***Expt.*** | ***ANSYS*** | ***% discrepancy*** |
| $O^0$ | No cutout | 9.7 | 10.63 | 9.58 |
| $30^0$ | No cutout | 6.64 | 8.18 | 23.19 |
| $45^0$ | No cutout | 5.98 | 7.51 | 25.58 |

| | | | | |
|---|---|---|---|---|
| $0^0$ | Circular cutout of 40 mm dia. | 8.55 | 9.14 | 6.9 |
| $30^0$ | Circular cutout of 40 mm dia. | 6.42 | 7.67 | 19.47 |
| $45^0$ | Circular cutout of 40 mm dia. | 5.86 | 6.90 | 17.7 |
| $0^0$ | Square cutout of 35 mm side | 7.72 | 9.03 | 16.96 |
| $30^0$ | Square cutout of 35 mm side | 6.23 | 7.54 | 21.02 |
| $45^0$ | Square cutout of 35 mm side | 5.62 | 6.56 | 16.72 |
| $0^0$ | Rectangular cutout of 30 x 40 mm size | 7.42 | 8.96 | 20.75 |
| $30^0$ | Rectangular cutout of 30 x 40 mm size | 5.92 | 6.59 | 11.31 |
| $45^0$ | Rectangular cutout of 30 x 40 mm size | 5.24 | 6.06 | 15.64 |

*B. Discussion of results*

*(a) Composite plates without cutouts*

The values of the critical buckling stress for various composite plates with no cutouts are shown in Fig.3.

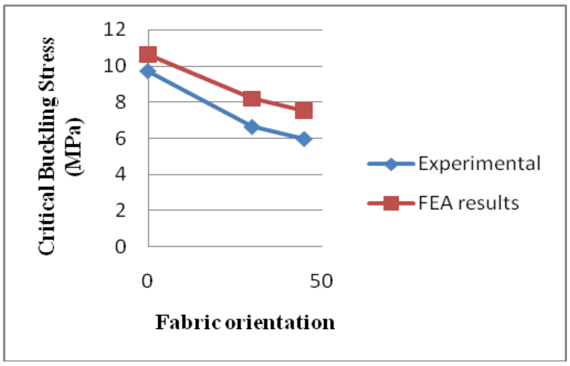


Fig.3: Critical buckling stress v/s Fabric orientation for composite plates with no cutouts

The buckled shape of a typical composite plate obtained in ANSYS is shown in Fig. 4 for $0^0$ fabric orientation.

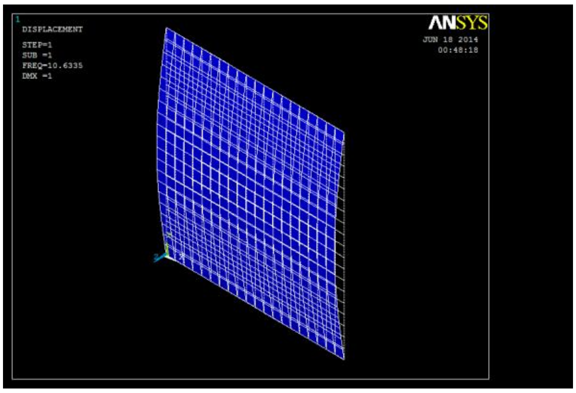


Fig.4: Buckled shape of plate with $0^0$ fabric orientation.

From Table 3 and Fig.3, the following observations are made:

- The values of critical buckling stress given by FEM are higher than the experimental values for all fabric orientations.
- The discrepancy between experimental and FEM values is least for $0^0$ fabric orientation (9.58%). The discrepancy is moderate for all fabric orientation angles.
- The critical buckling stress decreases as the fabric orientation angle increases. It is maximum for $0^0$ fabric orientation.



***(b) Composite plates with circular cutouts***

The values of the critical buckling stress for various composite plates with circular cutouts are shown in Fig.5.

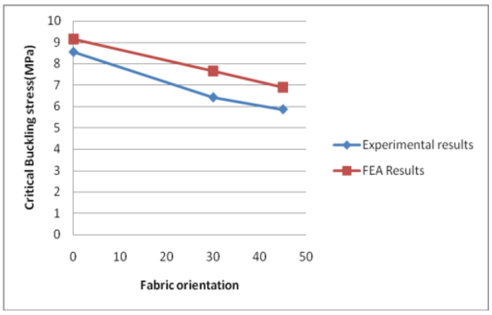


Fig.5: Critical buckling stress v/s Fabric orientation for composite plates with circular cutouts

The buckled shape of a typical composite plate obtained in ANSYS is shown in Fig.6 for $30^0$ fabric orientation.

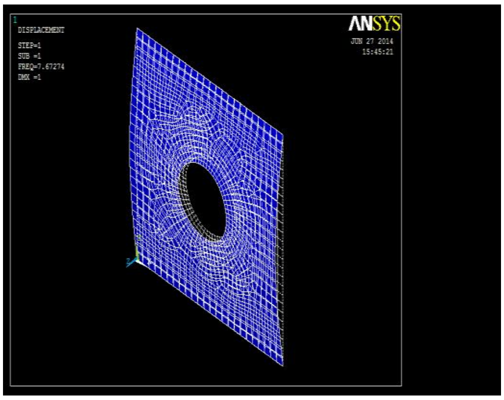


Fig.6: Buckled shape of plate with $30^0$ fabric orientation.

From Table 3 and Fig.5, the following observations are made:

- The values of critical buckling stress given by FEM are higher than the experimental values for all fabric orientations.
- The discrepancy between experimental and FEM values is least for $0^0$ fabric orientation (6.9%). The discrepancy is moderate for higher fabric orientation angles.
- The critical buckling stress decreases as the fabric orientation angle increases. It is maximum for $0^0$ fabric orientation.

*(c ) Composite plates with square cutouts*

The values of the critical buckling stress for various composite plates with circular cutouts are shown in Fig.7.

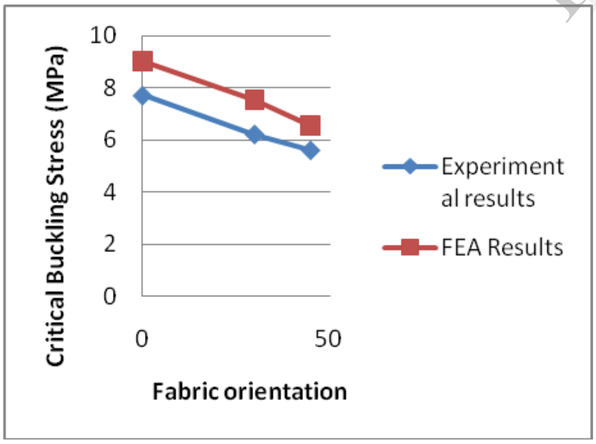


Fig.7: Critical buckling stress v/s Fabric orientation for composite plates with square cutouts

The buckled shape of a typical composite plate obtained in ANSYS is shown in Fig.8 for $45^0$ fabric orientation respectively.

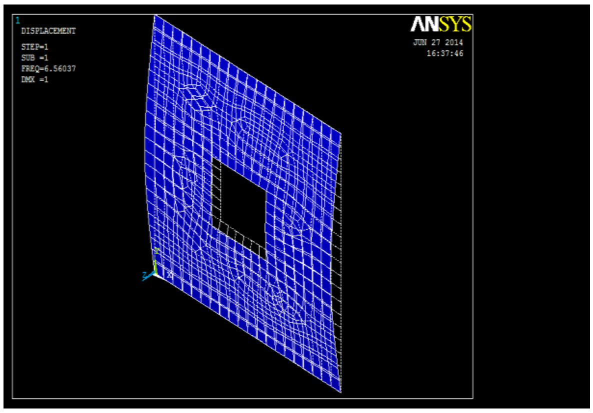


Fig.8: Buckled shape of plate with $45^0$ fabric orientation.

From Table 3 and Fig.7, the following observations are made:

- The values of critical buckling stress given by FEM are higher than the experimental values for all fabric orientations.
- The discrepancy between experimental and FEM values is least for $45^0$ fabric orientation (16.72%) and greater for other fabric orientation angles. The discrepancy is moderate for all fabric orientation angles.
- The critical buckling stress decreases as the fabric orientation angle increases. It is maximum for $0^0$ fabric orientation.



*(d) Composite plates with rectangular cutouts*

The values of the critical buckling stress for various composite plates with circular cutouts are shown in Fig.9.

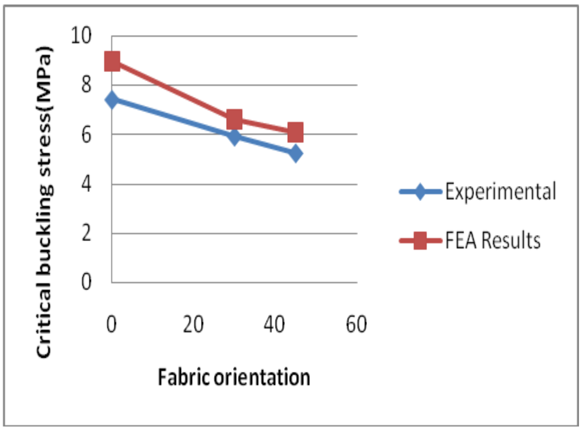


Fig.9: Critical buckling stress v/s fabric orientation for composite plates with rectangular cutouts

From Table 3 and Fig.9, the following observations are made:

- The values of critical buckling stress given by FEM are higher than the experimental values for all fabric orientations.
- The discrepancy between experimental and FEM values is least for $30^0$ fabric orientation (11.31%).

The discrepancy is moderate for all fabric orientation angles.

- The critical buckling stress decreases as the fabric orientation angle increases. It is maximum for $0^0$ fabric orientation.

*C. Effect of shape of holes on buckling of plates with $0^0$ fabric orientation*

Fig. 10 shows the experimental and FEM values of critical buckling stress for composite plates having $0^0$ fabric orientation with no hole, circular hole, square hole and rectangular hole.

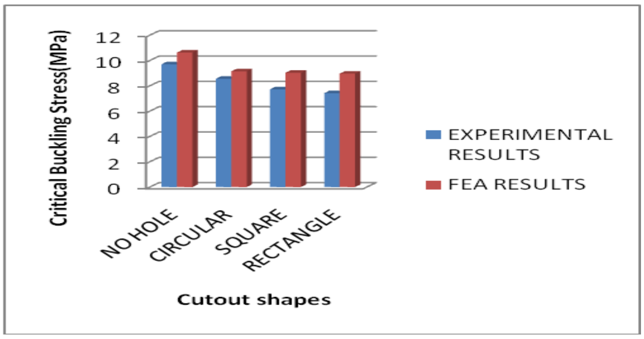


Fig.10: Critical buckling stress V/S cutout shape ($0^0$ fabric orientation)

From Table 3 and Fig.10, it is observed that the critical buckling stress is maximum for plate without hole and the critical stress reduces for plates with holes. The value of critical buckling stress is not very different for plates with square and rectangular holes. The value for plate with circular hole is higher compared to those for plates with square and rectangular holes.

*D. Effect of shape of holes on the buckling of plates with $30^0$ fabric orientation*

Fig. 11 shows the experimental and FEM values of critical buckling stress for composite plates having $30^0$ fabric orientation with no hole, circular hole, square hole and rectangular hole

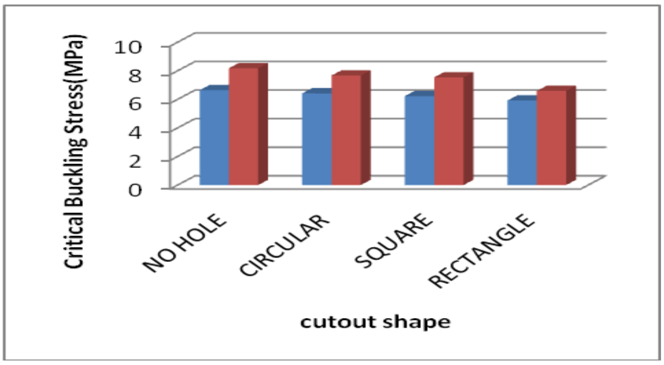


Fig.11: Critical buckling stress V/S cutout shape ($30^0$ fabric orientation)

From Table 3 and Fig.11, it is observed that the critical buckling stress is maximum for plate without hole and the stress reduces for plates with holes. The value of critical buckling stress is not very different for plates with holes. The value for plate with circular hole is higher compared to those for plates with square and rectangular holes.

*E. Effect of shape of holes on the buckling of plates with $45^0$ fabric orientation*

Fig. 12 shows the experimental and FEM values of critical buckling stress for composite plates having $45^0$ fabric orientation with no hole, circular hole, square hole and rectangular hole.

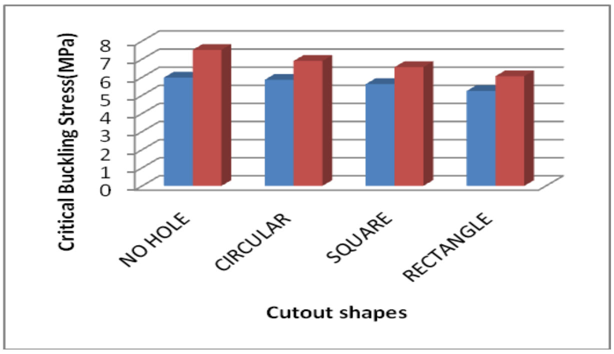


Fig.12: Critical buckling stress V/S cutout shape ($45^0$ fabric orientation)



From Table 3 and Fig. 12, it is observed that the critical buckling stress is maximum for plate without hole and the stress reduces for plates with holes. The value for plate with circular hole is higher compared to those for plates with square and rectangular holes.

## IV. CONCLUSIONS

From the present numerical and experimental studies, the following conclusions are made:

- For all composite plates considered here, the value of critical buckling stress or load given by FEM is higher than the corresponding experimental value.
- The critical buckling stresses given by both experimental and finite element methods decrease monotonically as the fabric orientation angle increases. The values are maximum for $0^0$ fabric orientation and minimum for $45^0$ fabric orientation.
- The values of critical buckling stress given by experiment and FEM reduce when cutouts/holes are introduced in the composite plates. The reduction in the value of critical buckling stress is quite significant.
- The shape of the hole does influence, although not significantly, the critical buckling stress when the areas of the holes are almost same. The plate with circular hole yields higher value when compared with a plate with square/rectangular hole.

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REFERENCES

[1] K. K. Shukla, Y. Nath, E. Kreuzer and K. V. Sateesh Kumar, "Buckling of Laminated Composite Rectangular Plate", Journal of Aerospace Engineering, Vol.18:215, 2005.

[2] Chainarin Pannok and Pairod Singhatanadgid, "Buckling analysis of composite laminate rectangular and skew plates with various edge support conditions", The 20th Conference of Mechanical Engineering Network of Thailand, 18-20, 2006

[3] Buket Okutan Baba and Aysun Baltaci, "Buckling characteristics of symmetrically and anti-symmetrically laminated composite plates with central cutout", Applied Composite Materials, 14:265–276, 2007.

[4] C.W. Pein and R. Zahari, "Experimental investigation of the damage behavior of woven fabric glass/epoxy laminated plates with circular cut-outs subjected to compressive force", International Journal of Engineering and Technology, Vol. 4, No. 2, pp.260-265, 2007.

[5] Murat Yazic, "Buckling of Square Perforated Thermoplastic Composite Plates", Journal of Reinforced Plastics and Composites, 27; 1059, 2008.

[6] Ganesan.C and P.K.Dash, **"**Elasto Buckling Behaviour Of Gfrp Laminated Plate With Central Holes", International Journal of Mechanical & Industrial Engineering, Volume-1 Issue-1, 2011.

[7] Priyanka Dhurvey and N D Mittal, **"**Buckling Behavior of an Orthotropic Composite Laminate using Finite Element Analysis", International Journal of Scientific Engineering and Technology, Volume No.1, Issue No.4, pg : 93-95, 2012.