Buckling Analysis of Edge Cracked Sandwich Plate

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ABSRACT

This work presents mainly the buckling load of sandwich plates with or without crack for different cases. The buckling loads are analyzed experimentally and numerically by using ANSYS 15. The experimental investigation was to fabricate the cracked sandwich plate from stainless steel and PVC to find mechanical properties of stainless steel and PVC such as young modulus. The buckling load for different aspect ratio, crack length, cracked location and plate without crack found. The experimental results were compared with that found from ANSYS program. Present of crack is decreased the buckling load and that depends on crack size, crack location and aspect ratio.

Keywords: sandwich plate, buckling load, cracked plate

تحليل الانبعاج للصفائح الشطيرية الحاوية على شق

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الخلاصة

هذه الدراسة ركزت بشكل رئيسي على تحليل حمل الانبعاج للصفائح الشطيرية بوجود ابو بدون شق لمختلف الحالات . وقد تم تحليل حمل الانبعاج عمليا وعدديا بواسطة برنامج الانسزز (ANSYS 15). في الجانب العملي تم تصنيع الصفائح الشطيرية ذات الشقوق من مادة ستينلس ستيل stainless steel ومادة PVC وقد تم ايجاد معامل المرونة لكل منها وايجاد حمل الانبعاج للصفائح الشطيرية لحالات مختلفة من نسبة الطول للعرض وطول شق وموقع الشق للصفائح الحاوية على شق وصفيحة غير حاوية على شق ومقارنة النتائج العملية مع برنامج الانسزز(ANSYS). أن وجود الشقوق يقلل من حمل الانبعاج بالاعتماد على حجم الشق وموقعه ونسبة الطول للعرض.

الكلمات الرئيسية: صفائح الشطيرية، حمل الانبعاج،صفائح حاوية على شق.

1. INTRODUCTION

Sandwich structures occupy a large proportion of composite materials design. They were very light weight and high flexural rigidity, excellent thermal isolation characters but the risk of buckling is greater than for classical structures. **Daniel, et.al, 2003.**

The transition of the plate from the stable state of equilibrium to the unstable one is referred to as buckling or structural instability. The smallest value of the load producing buckling is called the buckling load. According to this formulation, the critical load is the smallest load at which both the flat equilibrium configuration of the plate and slightly deflected configuration are possible. **Ventsel,** and **Krauthammer, 2001**. The behavior of plates are affected by presence of defects such as cracks due to corrosion, chemical attack, fatigue, impact and imperfections.

Many research had studied buckling analysis of plate. **Kumar, et al., 2004,** investigated plates behavior with various type of crack, like edge crack and central crack under different types of loading. They calculated buckling loads using hierarchical trigonometric functions. **Hiraman, et al., 2004,** studied quasi-static buckling tests were performed on natural fibre sandwich composites without delamination, with single delamination and with two delamination were prepared. From the results obtained it is evident that natural fibre structures without delamination displayed the highest load approximately 90% higher than the samples with delamination.

Nathera, 2011, investigated buckling phenomenon of cracked plates under compression load numerically using ANSYS by calculating the effect of crack length and crack location (i.e. cracks parameters) as well as the direction of load parallel or perpendicular to the crack faces. It is found from the results which are shown graphically in figures that the crack parameters and loading direction have significant effects on the critical buckling load (i.e. increased or decreased) of compressed cracked plate. **Ole, et al., 2012** described the development of a semi-analytic buckling model for steel-elastomer sandwich plate using the Rayleigh-Ritz method. All combinations of in-plane tensile, compressive and shear loads are measured. The model has been implemented in a FORTRAN program and the results have been compared with these obtain from the finite element program ABAQUS. **Nathera,** and **Saddam, 2012,** In this work, the buckling behavior for edge cracked plates with compression loading is studied numerically using ANSYS considering the effect of the crack parameter (i.e. size, location and orientation), aspect ratio of plate and boundary conditions. The results are shown that the crack parameters, aspect ratio of plate and boundary condition are efficient factors on the buckling load coefficient.

Hatem, and **Nawal, 2014,** studied the effect of using two skins material on the strength of sandwich plates with the effect circular hole when the mechanical loads are applied. Theoretically, numerically by ANSYS and experimentally are done for many cases of sandwich plates. The sandwich plates under bending or buckling load determine experimentally. The results showed that the stress concentration that occur in in hole weaken the strength of sandwich plate is depending on the size of hole and the face materials. **Shariati, et.al., 2014,** the buckling and post-buckling behaviors of cracked stainless-steel plates under uniform axial compression load were investigated experimental and numerical and parameter effects such as length of crack, crack angle, position of crack, plate imperfection, load band, and thickness of plate on the critical buckling load were analyzed. In the experimental work, mechanical

properties and plastic behavior of plates made from stainless steel were determined for the numerical study. Results are shown the considerable effects of the above parameters on the critical buckling load.
The present work focuses on how to evaluate buckling load for sandwich plate with crack experimentally and numerically. Mechanical properties for stainless steel and PVC are determined experimentally. Compression test done to find critical buckling load for different cases.
Also Finite element coded by ANSYS15.0 used to find it. According to author's knowledge about the published papers on the buckling field, there is no report on the buckling analysis of edge cracked sandwich plate.

2. NUMERICAL ANALYSIS

2.1 Element Selection and Modeling

Finite element method has been employed to analyze buckling load (critical loads at which a plate becomes unstable). The model was developed in ANSYS 15.0 using the element called shell281 as shown in **Fig.1** which is suitable for analyzing thin plate to moderately thick plate. The element has eight nodes at each node there were six degrees of freedom: translations in the global coordinate x is directed along the width of the plate, while the global y coordinate is directed along the length and the global z direction corresponds to the thickness direction, and rotations about the x, y, and z axes. It may be used for modeling that has layered applications such as composite shells. It is include the effects of transverse shear deformation. The accuracy in modeling composite shells is governed by the first order shear deformation theory. The shell section allows for layered shell definition, options are available for specifying the thickness, material, orientation through the thickness of the layers.
There were four steps for the eigenvalue buckling in ANSYS 15.0:

1. Build up the model: it includes defining element type (shell 281), material properties (young modulus and poison ratio of steel and aluminum) and models.
2. Solution (static analysis): includes made boundary conditions, applying loads and the analysis solve.
3. Eigen buckling analysis: from eigenvalue buckling analysis can be found the theoretical buckling strength of the plate.
4. Postprocessor: these steps includes listing result such as buckling loads and viewing mode shape of buckling , it can be plot the deformed and un-deformed shape of laminated plate.

2.2 Mesh Convergence

A convergence study was performed to determine the appropriate finite element mesh to be used in the buckling analysis of sandwich plate model. Meshes were developed, with increasing numbers of elements in the x and y directions and the buckling load for each of these models is shown in **Fig. 2**.

When increasing the degree of freedom from (576) to (2046) the difference in buckling load is only a (0.036%). No difference observed between D.O.F. (2046) and D.O.F. (4416). The buckling load for each of these models is shown in **Table 1**. This indicates that D.O.F. (2046) is capable of performing the analysis within a reasonable degree of accuracy.

2.3 Verification Case Studies

In the present study, Series of preselected cases are modeled to verify the accuracy of the method of analysis. The results of **Nathera, and Saddam, 2012** are compared to numerical solution (ANSYS).see **Table 2** from these results, it is obvious that the methods of solution gives better results for numerical solution.

3. EXPERIMENTAL WORK

In the present work, three- purposes were investigated. First, to outline the general steps to manufacture models are then used to evaluate the young modulus of steel and PVC alone. Second, design and fabricate the sandwich plate from stainless steel and PVC and made different cases of crack. Third, the buckling test can be done to calculate the critical buckling load of sandwich plate for simply free boundary conditions with or without crack.

3.1 Tensile Test

Test specimens were cut from the plates using cutting tool CNC machine shown in **Fig. 3.** The two samples one made of steel and the second made of PVC are divided according to dimensions, as set by ASTM-E8 as in **Fig. 4.** The specimen's tensile test is mounted vertically in a servo-hydraulic testing machine, and hydraulically pulled with stroke control with large steel grips, tensile machine shown in **fig. 5** Maximum capacity (50KN). The results (the young modulus) are listed in **Table 3**.

3.2 Manufacturing the Sandwich Plate

A sandwich structure results from the assembly by bonding-or welding-of two thin facings or skins on a lighter core that is used to keep the two skins separated. The facing materials are from stainless steel, and the core materials is from PVC it is as light as possible. One can denote couples of compatible materials to form the sandwich. The difference between the skins (faces) and the core in the mechanical properties is closed by the range of the ratio of Young modulus of faces to the Young modulus of core **Daniel, et.al, 2003**

$$10 \leq {E_f}/{E_c} \leq 100 \qquad \textbf{(1)}$$

To determine the ratio in **Eq. (1),** stainless steel alloy is selected to be the constitutional materials of faces while PVC is represented the core. To obtain the mechanical properties of each constitution materials, tensile test is done. The faces and core are cut, a small cut has been added to the each specimens using suitable cutting tool, as shown **Fig. 6**. The ferton power tools, with (330 W) power and (10000-32000 r.p.m) has been used to create cracks in the plates. The crack width equal to thickness of cutter disc (d=2mm). Then, bonded the two stainless steel faces with PVC core by cyanoacrylate adhesive shown in **Fig. 7** and press them until the adhesive material dried.

3.3 Buckling Test:

The specimen was loaded in axial compression (vertical direction) using tensile test machine of (200 kN) capacity shown in **Fig. 8** The specimen was simply supported at two ends and kept free at the other two ends. The specimen was loaded slowly until buckling. Simply supported boundary conditions were simulated along the top and bottom edges. For axial loading, the test specimen was placed between two extremely stiff machine heads of which the lower one was fixed during the test, whereas the upper head was moved downwards by servo hydraulic cylinder. The sandwich plate was loaded at constant cross-head speed of (3 mm/min) .The experimental set up as shown in **Fig. 9.**

4. RESULTS AND DISCUSSION

4.1 Aspect Ratio

Fig.10 for S-F-S-F sandwich plates with central 5mm edge crack show that the buckling load decreases when a/b increase with high percentage reaches to 37. 45% when the aspect ratio increase from 1 to 2. 32.64% On the other hand when a/b varies from 1 to 1.5, and 1.5 to 2, the decreasing of buckling load 6.85% and 32.64% respectively. The difference between ANSYS program and experimental result is 3.4%, 4.9%, 2.5% for aspect ratio 1, 1.5 and 2 respectively.

4.2 Crack Location

It is shown from **Fig.11** that the buckling load for S-F-S-F sandwich plate with 5mm edge crack decreases when crack location change from $a/4$to$a/2$ (i.e, 55mmto 110mm) with small percentage 0.4% . It can be also observed that the buckling load is increase with small percentage when crack location varies from $a/2$to $3\,a/4$(i.e., 110mmto 165mm) reach to (0.13%). The buckling load for the cases $a/4$and $3\,a/4$ is approximately equal. These result show that the buckling load is effected with crack location with very small percentage.

4.3 Crack Size

It is shown from **Fig.12** that the buckling load for S-F-S-F sandwich plate with central edge crack decreases when crack size increase change from 5mm to 10mm with small percentage 1.3% . It can be also observed that the buckling load is decrease with small percentage when crack size varies from 10mm to 15mm reach to (1.9%). The buckling load when they were no crack is the large value and it decreases by 4.4% when adding 5mm central edge crack see **Table 4.**

5. CONCLUSION

In the present work, the buckling behavior of the edge cracked sandwich plate made from stainless steel and PVC has been considered. The effect of some parameters such as aspect ratio, crack location and crack length for S-F-S-F supported boundary conditions on the critical buckling load of compressed cracked plates have been investigated experimentally and numerically using Finite Element Method (ANSYS Package). It is shown from the computed results that:

1. The buckling load is very sensitive to aspect ratio change. When the aspect ratio increases the critical buckling load decreases. And maximum buckling load occurs in square plate.

2-Small crack have a little effect on the critical buckling load and it becomes higher for larger crack and the buckling load became lower and more dangerous more than the case that is no crack.

3- The crack location is the most an effective parameters on the buckling load.

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NOMENCLATURE

a, b= Dimension of plate in x and y coordinate, m.

E= Elastic Young modulus,GPa.

E_f, E_c= Elastic Young modulus for face and core, GPa.

t= Thickness, m.

Nxx, Nyy, Nxy= The resultant of in-plane force per unit length, N/m

D.O.F. = Degree of freedom, dimensionless.

S-F-S-F= simply free simply free

v= Poison ratio, m/m.

k= Buckling coefficient, dimensionless,

C= Crack size, m.

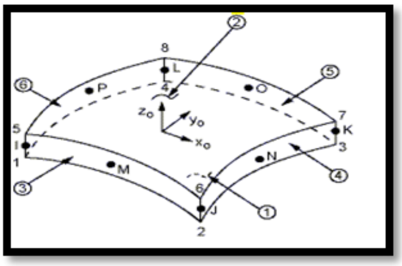


Figure 1. Shell281 Geometry [ANSYS 15.0 Program]

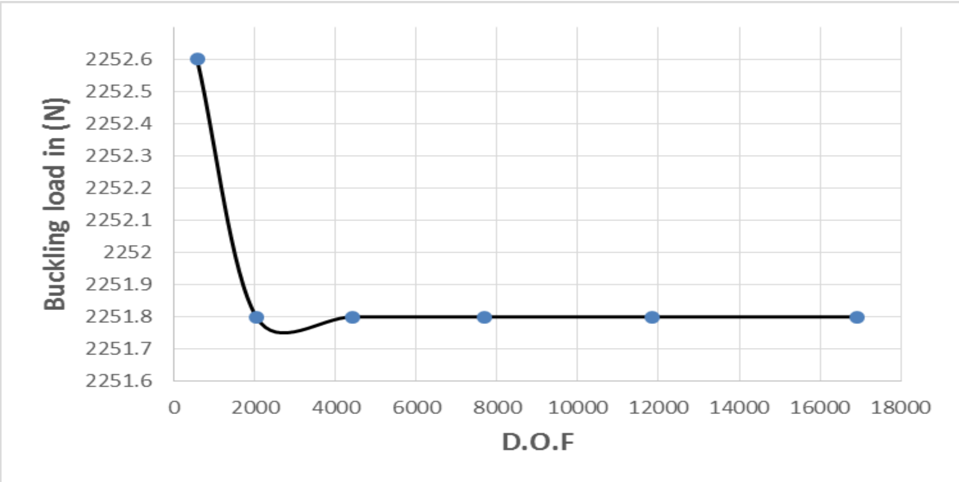


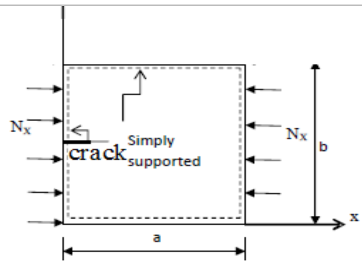
Figure 2. Convergence study of Buckling load versus D.O.F. for S-F-S-F plate without crack

Table 1. Buckling load convergence study for S-F-S-F plate without crack

No. of element	No. of node	D.O.F	Buckling load (N)
25	96	576	2252.6
100	341	2046	2251.8
225	736	4416	2251.8
400	1281	7686	2251.8
625	1976	11856	2251.8
900	2821	16926	2251.8

Figure 3. Cutting tool CNC machine

Table 2. Buckling coefficient $k = \frac{12b^2(1-\upsilon^2)N_x}{\pi^2 E t^3}$ of simply supported edge cracked plate

c/a	Nathera, 2012	Present [ANSYS15.0]	
0.1	4	3.823	
0.2	3.98	3.754	
0.3	3.96	3.687	
0.4	3.9	3.613	E=200GPa , t=10mm, υ=0.3, a/b=1
0.5	3.69	3.5	

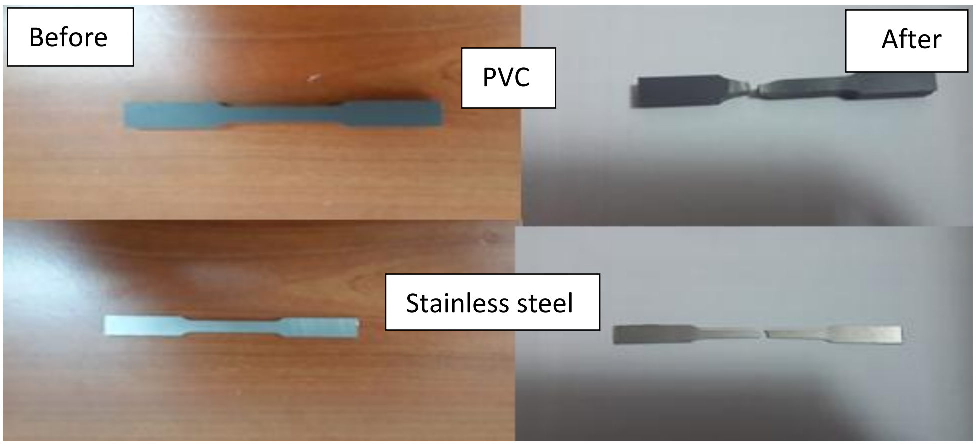


Figure 4. Samples of tensile test one made of steel and the second made of PVC.

Figure 5. Tensile test machine

Figure 6. The ferton power tools

Figure 7. Cyanoacrylate adhesive

Figure 8. Buckling test machine

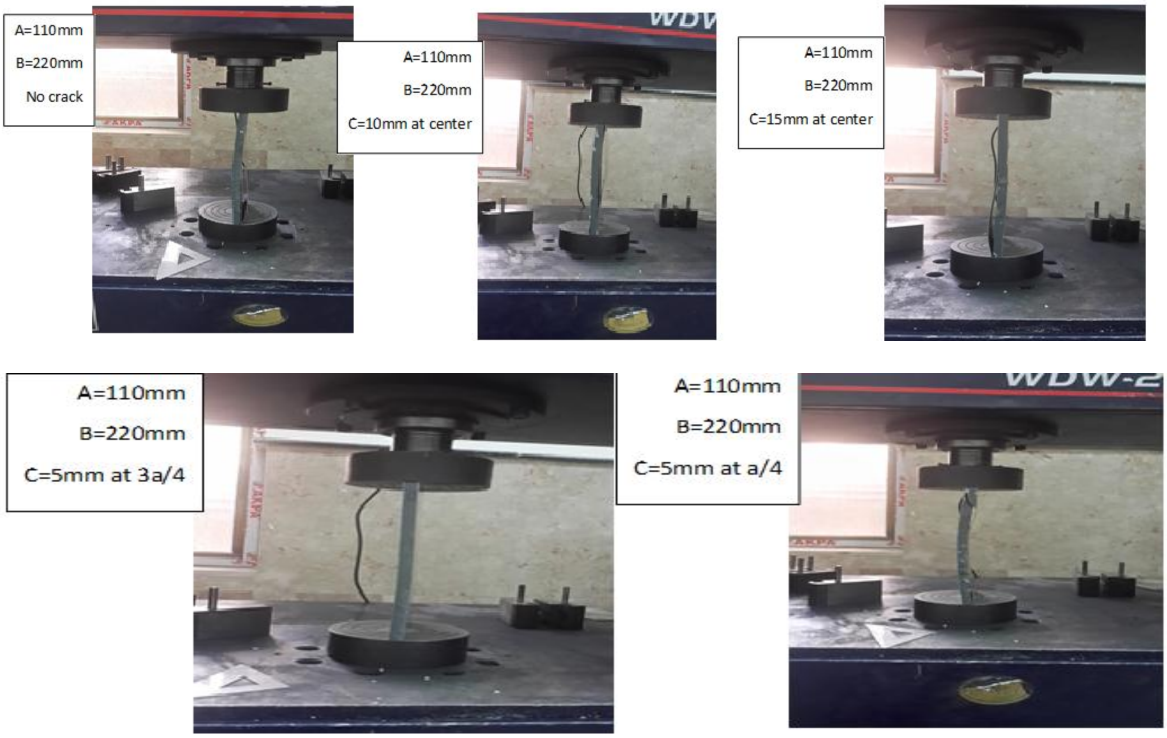


Figure 9. The experimental set up

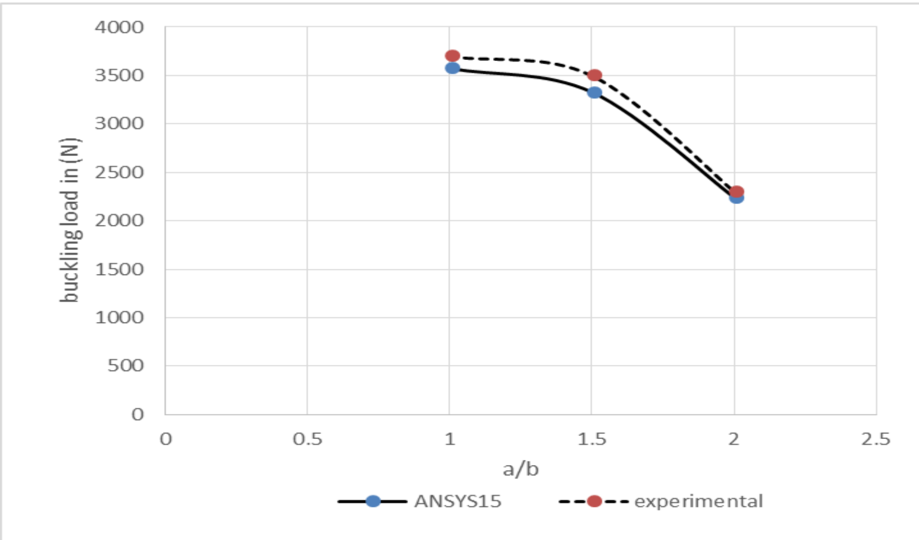


Figure 10. Effect of aspect ratio on buckling load for S-F-S-F sandwich plate with (5mm) central edge crack

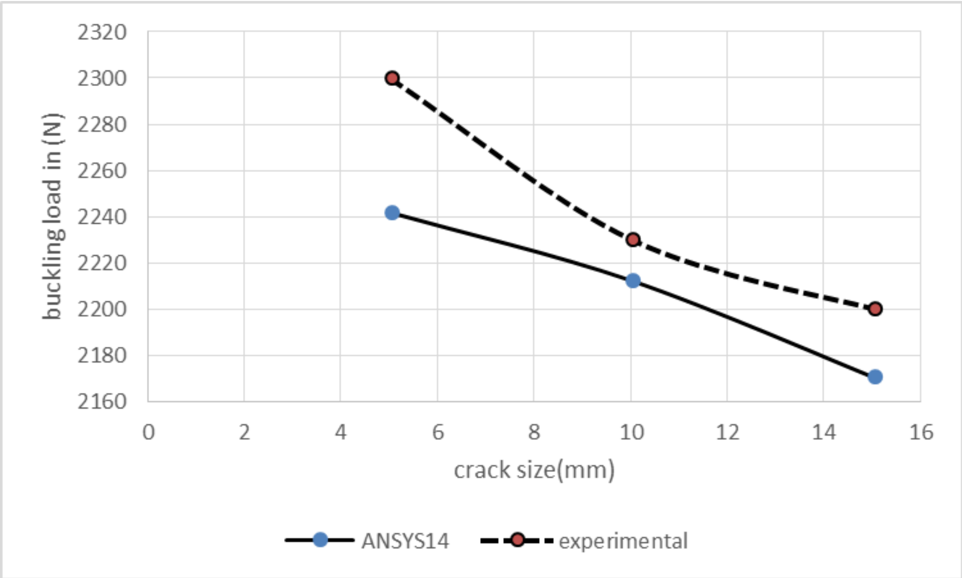


Figure 11. Effect of crack size on buckling load for S-F-S-F sandwich plate with central edge crack and a=110mm, b=220mm

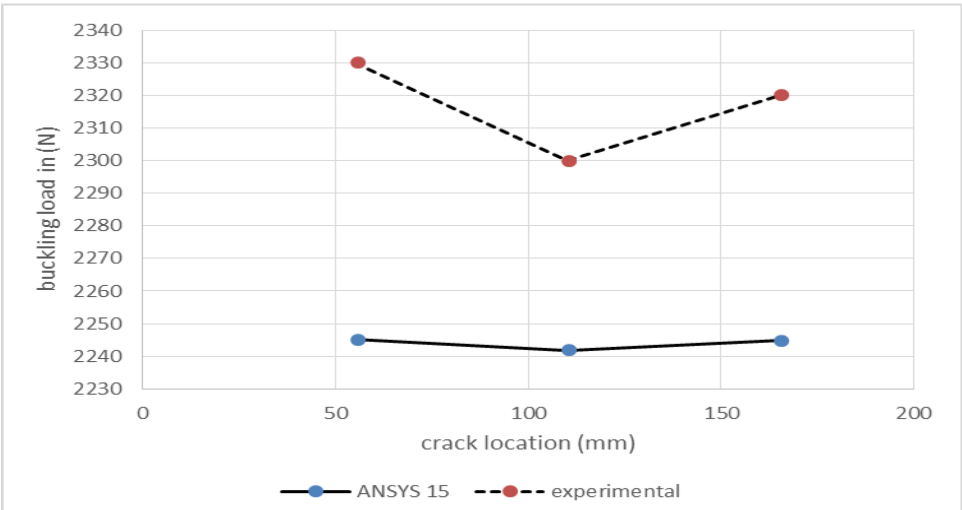


Figure 12. Effect of crack location on buckling load for S-F-S-F sandwich plate with (5mm) edge crack and a=110mm, b=220mm

Table 4. Buckling load of S-F-S-F sandwich plate without crack and different central crack size a=110mm, b=220mm

No. of element	Buckling load (N) experimentally	Buckling load (N) in ANSYS15.0	Error%
no crack	2500	2251.8	9.93
5	2300	2241.9	2.53
10	2230	2212.4	0.79
15	2200	2170.7	1.3