# Buckling of Anisotropic/Isotropic Sandwich Plate Assemblies under Shear Loading

Mine Uslu Uysal

***Abstract*—**This paper presents a finite element method (FEM) of adhesively bonded sandwich panel under shear loading. 3D finite element models for the sandwich panel having isotropic or anisotropic (carbon reinforced epoxy) adherent plate have been established by ANSYS commercial program. Two types of the adhesive layers are used in the assembly, one of them is stiff adhesive and the other one is flexible adhesive layer. The effects of the adhesive type and isotropic/anisotropic adherent properties on the buckling loads have been investigated. Sandwich models' mode shapes are presented for the first four modes. The FEM analysis is based on the use of special surface to surface contact elements. In the numerical analysis, the buckling load values of the sandwich panel are obtained by using normal penalty stiffness that is chosen for contact elements in the adhesive layer. The results of sandwich panel show that buckling load varies with changing stiff/flexible adhesive layer and adherent material properties.

***Keywords*—**Anisotropic plate, finite element model, sandwich structures, shear buckling

## I. Introduction

CARBON reinforced epoxy composites have recently come to the fore owing to a set of interesting characteristics over conventional materials. In fact, carbon-epoxy composites are being increasingly used in structures requiring high specific strength and stiffness, such as in the automotive, marine, military and aerospace industries. Carbon-epoxy composite materials are used as a sandwich structure by adhesively bonding with aluminum on the structural components of aviation aircraft [1]. Sandwich construction is one of the most functional forms of composite structures developed by the industry. The aim of sandwich construction is to use the materials with maximum efficiency while the particular attention is paid to increase the structural strength/to reduce the structural weight as much as possible. Sandwich structures are widely used in variety of industries because of their advantage which is higher buckling resistance, compared to monocoque thin-walled constructions. The major advantage can be very affected in industrial application where high stability is a leading requirement. These joints must be designed carefully. Plate buckling is a phenomenon that occurs in the thin plates supported on four sides when subjected to forces. The plate will return to the initial position when the force does not act any more. It is valid only when applied force is smaller than the critical plate-buckling force. If the applied force is higher, the plate will remain in the deformed position forming buckles.

The structural analyses of sandwich construction have been a highly active research topic in literature. Some studies dealing with fundamental theoretical approaches, governing differential equations and boundary conditions for buckling were published in 1940s. Reissner [2], Libove and Batdoff [3] and Eringen [4] were among the researchers. However, the assumption was that the faces and the core were of isotropic materials. In the 1970s, Allen [5] and Plantema [6] published their books about buckling and local instability problems based on knowledge at that time. Most recently, during 1990s, Bitzer [7], Vinson [8] and Zenkert [9], [10] published their studies interested in sandwich constructions and their buckling behaviors. Corden [11], Marshall [12], Frostig [13], Librescu and Hause [14] contributed to the advanced sandwich structures, post buckling and sandwich model optimizations with their articles. There is vast literature on the sandwich structures made of isotropic materials analytical and numerical solutions.

Also, some researcher used commercially available finite element packages to conduct buckling analysis. Herencia et al. [15] performed buckling analysis using quadrilateral shell elements having 4 nodes on MSC/NASTRAN, Lanzi and Giavotto [16] modeled composite panel based on 4 node shell elements in ABAQUES. Mallela and Upadhyay [17] conducted a study for in-plane shear buckling for composite plates in ANSYS by using 8-noded quadrilateral shell elements. Jain and Upadhyay [18] studied for in plane shear buckling on the composite structures. As can be seen, various buckling studies have been employed for sandwich panels. The rapid development and wide application of the sandwich structures indicate that knowledge of the mechanical strength of the sandwich structural is critical. Additionally, in practical conditions, most sandwich structures are subjected to shear loading. Particular case of plate buckling is sheared plate buckling where a plate under shear loading and also present study interested in shear buckling load on the anisotropic/ isotropic sandwich panel.

Materials can be used for the construction of adhesively bonded sandwich structures, depending on the type of application and the requirements. Metallic or non-metallic materials can be choice for two faces. Commonly preferred metallic materials used for the construction of the faces are steel alloys, stainless steel and aluminum. However, preferential non-metallic materials of choice are reinforced

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thermoplastics and fiber composites. Present study interested in adhesively bonded sandwich structure consists of two plates which are homogeny isotropic aluminum and anisotropic carbon-epoxy reinforced plastics material. The advantages of advanced anisotropic composite materials over isotropic conventional materials led to an extensive research on mechanical behavior of sandwich construction involving advanced composite materials. Some researchers, Pearce and Webber [19], [20], Roa and Piening [21] worked on the effects of anisotropy on mechanical behavior of sandwich structures.

This paper focused on, the buckling behaviors in the sandwich structures having isotropic or anisotropic adherent plates under shear loading. The detailed analysis models for buckling loads prediction were built up by using 3D finite element model based on contact element. Adherent materials were chosen isotropic and anisotropic material, also two different type of adhesive (stiff and flexible) were used in sandwich panels. The main objective of this study is to investigate adherent's anisotropy and stiff/flexible adhesive effect to increase the buckling load capacity. The buckling loads of all sandwich models were predicted for the first four modes and their mode shapes were presented.

## II. Finite Element Model

The present sandwich panel is formed by two adherent plates and a thin linear-elastic, isotropic adhesive layer in between. Adherent materials were chosen as aluminum alloy and carbon-epoxy reinforced composite and their properties are shown in Table I and Table II, respectively.

TABLE I
MATERIALS PROPERTIES OF ADHERENT TYPE I

| Aluminum Alloy 7075 | |
|---|---|
| Young's modulus (MPa) | 71700 |
| Poisson's ratio | 0.33 |
| Shear strength (MPa) | 152 |

TABLE II
MATERIALS PROPERTIES OF ADHERENT TYPE II [22]

| T300-934 Carbon-Epoxy | |
|---|---|
| Longitudinal young modulus, $E_{11}$ (MPa) | 148000 |
| Transversal young modulus, $E_{22}$ (MPa) | 9650 |
| Longitudinal shear modulus, $G_{12}$ (MPa) | 4550 |
| Longitudinal poisson's ratio, $\upsilon_{12}$ | 0.3 |

Loctite-Hysol 9464 and Terokal 5045 adhesive were used as stiff and flexible adhesives respectively. Material properties of adhesive are given in Table III.

TABLE III
MATERIAL PROPERTIES OF ADHESIVE TYPES [23], [24]

| Properties | Stiff Adhesive (Loctite-Hysol 9464) | Flexible Adhesive (Terokal 5045) |
|---|---|---|
| Young's modulus (MPa) | 1750 | 437 |
| Poisson's ratio | 0.36 | 0.38 |
| Shear strength (MPa) | 26 | 20 |

Geometry and dimension of the sandwich panel are shown in Fig. 1. The height "a" of the sandwich panel is 350 cm and the width b is 120 cm. The thickness of the adherents and adhesive are 8 mm and 1.5 mm, respectively and total thickness of sandwich panel t is 17.5 mm.

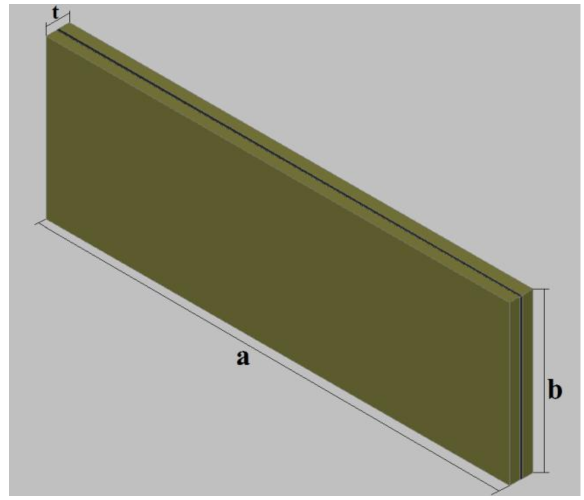

Fig. 1 Typical geometry of the sandwich panel assembly

Sandwich panel has supported 3 which is fixed for whole translation and rotation around x and y axes. Support 1, 2, 4 are fixed in y and z direction and for rotation around x and y axis (Fig. 2).

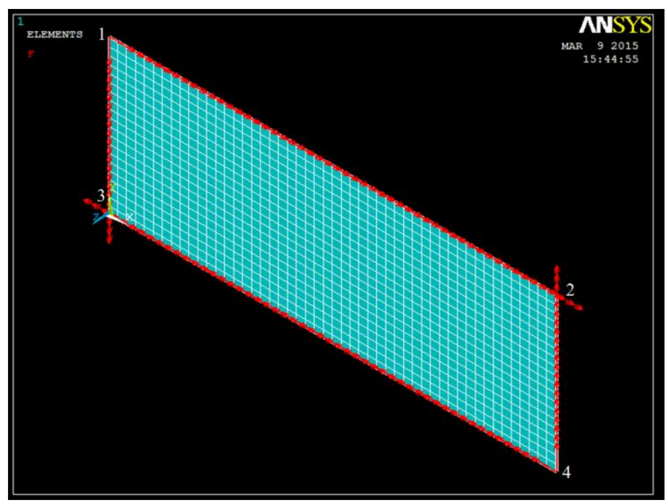

Fig. 2 Sandwich panel assembly under shear loading

The numeric models were divided in to finite number of elements, the mesh size was determined by solid element constraints that the length ratio of elements edges cannot be smaller than 1/20 and angle between element edges cannot be less than 70°. Also thickness lines were divided two layers of elements. Solid 95 element is used to modeling adhesive and adherent. The sandwich model has contact pairs; surface to surface contact elements (CONTA 174 and TARGE 170) were set the overlap surface the adherent and adhesive. These contact elements position can be seen Fig. 3. Contact elements use Gauss integration points by defaults, which generally provides more realistic results than the nodal detection scheme

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and they transmits contact pressure between gauss points, not forces between nodes [25]. CONTA 174 is 3D and 8 node, higher order quadrilateral element and they were generated on the bottom and upper surface of adhesive. TARGE 170 was used on the overlap surface of the adherents and it was used to represent various 3D target surfaces for associated contact element.

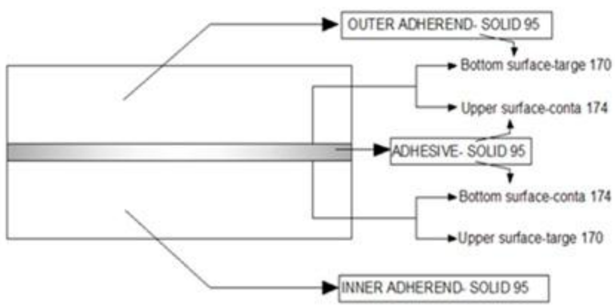


Fig. 3 Modeling of contact surface between adhesive and adherent

The contact algorithm method was selected as the Penalty Method because penalty function is a displacement based solution and it deals with contact stiffness and penetration. In ANSYS, contact stiffness is increased by the normal penalty stiffness factor, a default value of 1. FEM analysis must be repeat to obtain the optimal converge rate and acceptable penetration by changing the normal stiffness factor [26]. According the result from repeated by increasing the value of normal penalty stiffness factor was set to $10^7$ N/mm$^2$. Moura et al. [27] also recommended that the user have to be carefully chosen the normal stiffness factor for obtain a good performance of the model.

Debonding of two surfaces was not considered in present paper, sliding is not permitted and bonded contact always options in ANSYS was chosen for contact surface behavior between the adherent and adhesive layers.

## III. Numerical Results and Discussions

The effects of the adherent material and adhesive material on the buckling loads are presented in Figures 4-6. Sandwich panels were compared for the first four modes. Three types of sandwich panels were modeled such as AL/AL, C-Epoxy/C-Epoxy and AL/C-Epoxy panel pairs. These panels had two type adhesive layer (stiff and flexible adhesive) assumed to be a linear-elastic homogeneous isotropic. The shear buckling phenomena and global deformation behaviors of the sandwich model were studied. In the numerical analysis shear loading V=1 kN was applied and the response was calculated ignoring the large displacement effect and time varying load. Since a unit load was specified, the buckling load in the first mode was represented as the critical buckling load. The elastic buckling analysis was used to corresponding shear buckling shapes.

The buckling loads of the sandwich panels with stiff adhesive were examined for first four modes. Buckling loads values for mode 1 and mode 2 are presented in Fig. 4 and also mode 3 and mode 4 can be seen in Fig. 5.

As is known that, the critical buckling load appears in mode 1. In Fig. 4 show that all sandwich panels critical buckling loads. The critical buckling load value was 2282 N for sample AL/C-Epoxy sandwich panel. This value was determined 2612 N and 8323N for C-Epoxy/ C-Epoxy and AL/AL sandwich panel, respectively. Thus, critical buckling load is increased 14.46% when one adherent carbon-epoxy plate was constant and the other adherent plate material changed aluminum to anisotropic carbon-epoxy plate in sandwich structures.

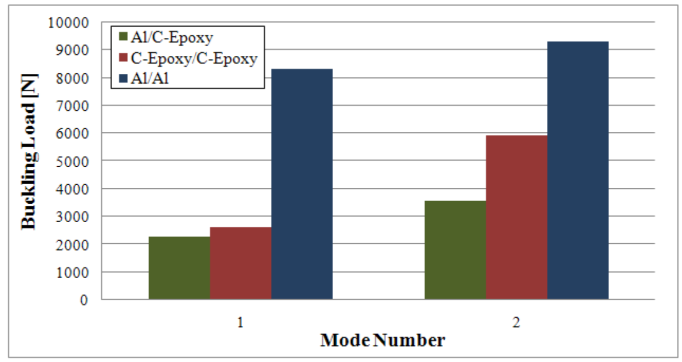


Fig. 4 Effects of the adherent in stiff adhesively sandwich plate on the buckling load, mode 1 and mode 2

As seen in Fig. 4 and Fig. 5, this increment was calculated as 65.91%, 33.90% and 13.95% for mode 2, mode 3 and mode 4, respectively. This result presented that as is known adherent material properties are very affected for the buckling load but also buckling load changing ratio should be handled with caution according the mode numbers. The highest changing ratio was determined in mode 2 for AL/C-Epoxy and C-Epoxy/C-Epoxy panels.

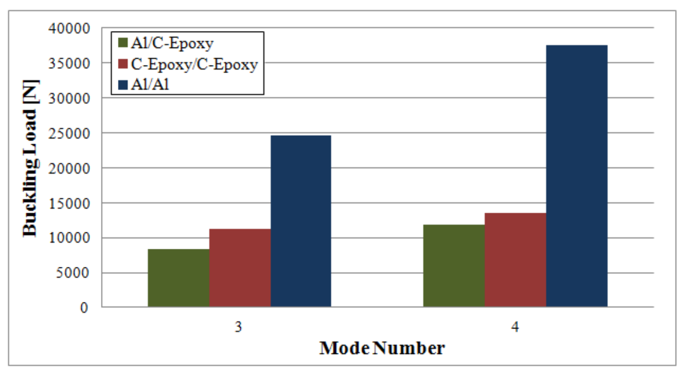


Fig. 5 Effects of the adherent in stiff adhesively sandwich panel on the buckling load, mode 3 and mode 4

When adhesive layer was chosen flexible, the buckling loads can be seen in Fig 6-8. The buckling load decreased 7.2% when the flexible adhesive was used instead of stiff adhesive on the AL-AL sandwich panel, for mode 4.( as can be seen Fig. 6) This decrease was obtained 3.1% and 3.7% for C-Epoxy/C-Epoxy, AL/C-Epoxy, respectively. These results revealed that the adhesive layer stiff/flexible properties in the sandwich panel subjected to shear loading plays a major role in the buckling load on the higher modes.

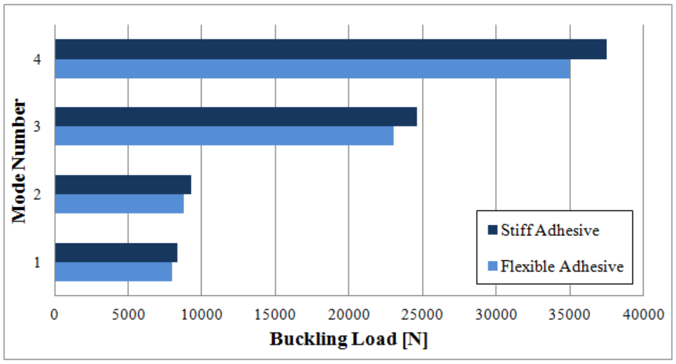


Fig. 6 Effects of the adhesive layer in Al-Al sandwich panel on the buckling load

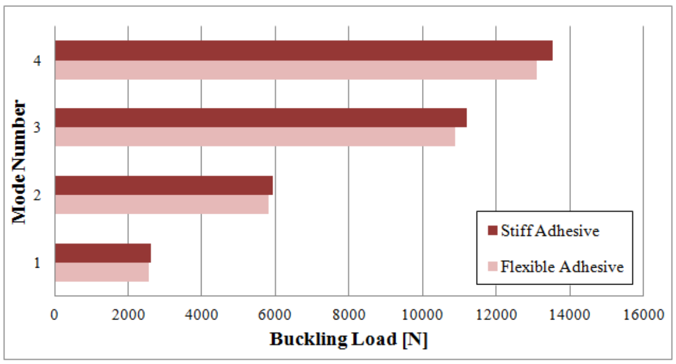


Fig. 7 Effects of the adhesive layer in C-Epoxy/C-Epoxy sandwich panel on the buckling load

Figures 6-8 show that the obtained buckling load values are sensitive to mechanical properties of the adhesive layer for all sandwich panel types. It can be seen that stiff adhesive layer condition, the obtained results were higher than flexible adhesive. Due to large deformations and lower critical buckling loads, the flexible adhesive layer in the sandwich panels have a limited potential under shear loading.

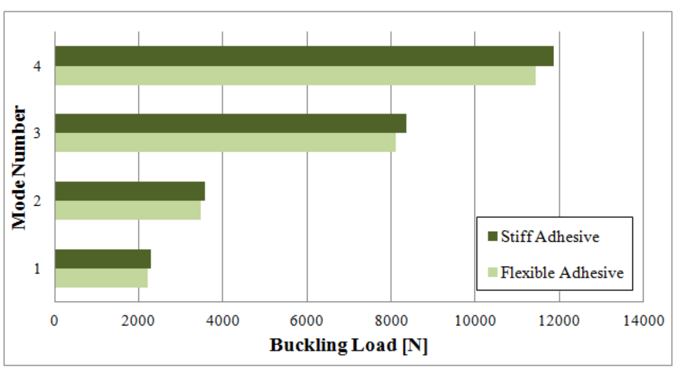


Fig. 8 Effects of the adhesive layer in Al/C-Epoxy sandwich panel on the buckling load

The maximum out of the plane deflection of the AL/AL, C-Epoxy/C-Epoxy and AL/C-Epoxy panel pairs with stiff adhesive layer for the first modes were presented in Figs. 9-11. In the homogeny isotropic AL-AL panel pair two semi-buckles were created. The one of them was in z direction (positive semi-buckle, red zone in Fig. 9) and the other was in –z direction (negative semi-buckle, blue zone in Fig. 9).

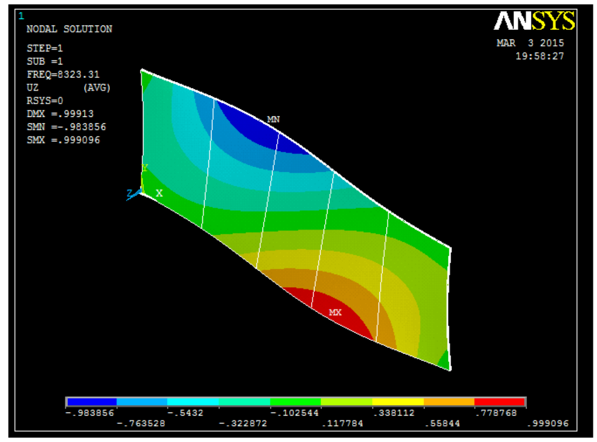


Fig. 9 Out of the plane deflection in stiff adhesively Al-Al sandwich panel on mode 1

As seen in Fig. 10 and Fig. 11 for different adherent materials, the maximum out of the plane deflection didn`t always occur at the same point, but it moved along the long edge on the top the semi-buckle.

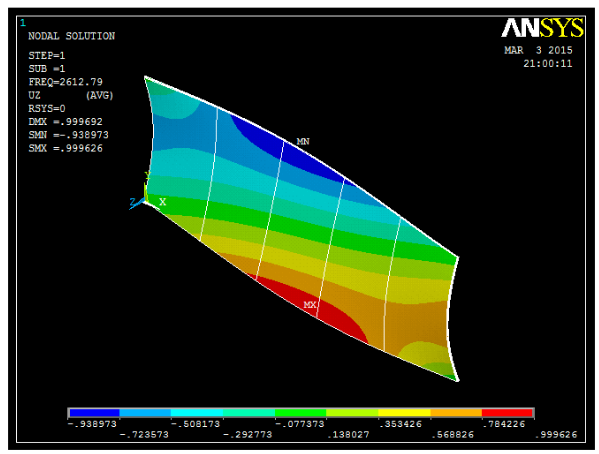


Fig. 10 Out of the plane deflection in stiff adhesively C-Epoxy/C-Epoxy sandwich panel on mode 1

The mode shapes were not similar for the isotropic and anisotropic sandwich panels, this case can be seen in Figs 9-11.

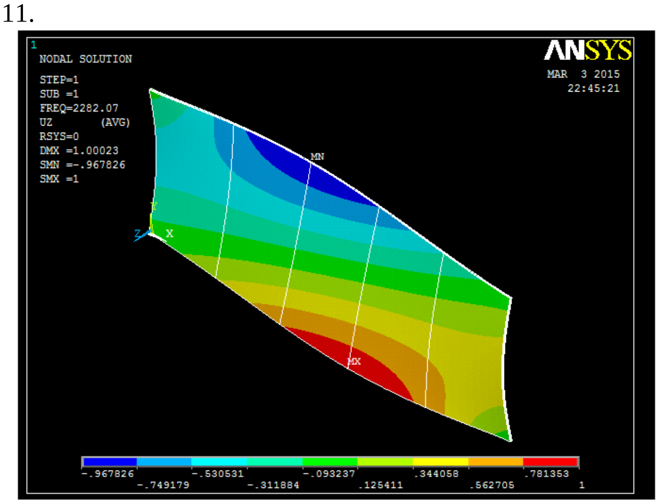


Fig. 11 Out of the plane deflection in stiff adhesively Al/C-Epoxy sandwich panel on mode 1

## IV. Conclusion

In this study, the buckling problem in sandwich structures subjected shear loading were investigated in detail by using finite elements model. In sandwich model, anisotropic carbon-epoxy composite was adhesively bonded with aluminum plate, this type sandwich structures uses as structural components in the field of aviation. Three types sandwich panel model were built up for buckling analyses. These sandwich panels are Al/Al, C-Epoxy/C-Epoxy, and Al/C-Epoxy. Also in the three sandwich model, two different types adhesive layer as stiff and flexible adhesive were used. Comparing the obtained results from the numerical investigation, it is seen that stiff adhesive sandwich structures have higher buckling loads than flexible adhesive sandwich structures. These increments were seen in the especially high modes. In addition, as is known that the adherent material affected buckling loads in the sandwich panels, but also the present analysis shows that buckling load changing ratio should be handled with caution according the mode numbers. Therefore, the choosing of the stiff/flexible adhesive layer and isotropic/anisotropic adherent material should be chosen carefully a sandwich plate under shear loading.

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