Research on thermal buckling behaviour of the adhesively bonded scarf joints for glass connections

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Abstract

Adhesively bonded technique is preferred more than bolted joining technique for glass connections. Glass panels supported by metal frame are generally used to glazing applications. Obtaining the critical buckling temperature is highly important and also thermal buckling behaviour of the glass joints should be considered. Stability of the joint is influenced by many design parameters such as types of adhesive/adherent materials. This paper presents a finite element method (FEM) of adhesively bonded scarf joint under thermal loading. Finite element models for the glass joint having isotropic (Aluminum and Steel) or anisotropic (Boron-epoxy, Kevlar-epoxy and E glass-epoxy) adherents were established by ANSYS® commercial program. FEM analysis was based on the usage of special surface to surface contact elements. The effects of adherent properties on the critical buckling temperature were investigated. Adhesively bonded scarf joint mode shapes were presented for the first five modes. Among the anisotropic adherent materials, the highest critical buckling temperature was determined for the boron-epoxy/glass joint. Additionally, the results showed that the adherent materials should be chosen carefully for adhesively bonded glass joints. Copyright © 2017 VBRI Press.

Keywords: Adhesively bonded scarf joint, joint design, thermal buckling, finite element analysis.

Introduction

Glass is used as unique structure elements in contemporary architecture such as roofs, stairs, beams and columns in recent years. Many architects have attempted to design transparent buildings driven by the idea of increasing the clearness, achieving the impression of building lightness. In these buildings, transparent glass walls have been used a physical barrier between the surrounded nature and interior living space. However, at the end of the last century, the glass walls is not only as space barrier and building envelope, but also in a structural manner as primary element capable and transfer the imposed loads. Recently, few researches have been undertaken to improve the understanding of the glass panel behaviour subjected to loading. For instance, the glass stiffness was studied by experimentally and analytically in a steel framework in transparent buildings [**1,2**]. Englhardt [**3**] studied buckling behaviour for glass plates with loading over the whole length. Wellershoff et al. [**4**] studied the utilization of the glass panels in space grid structure to cover the public areas without any columns and steel cables. Glass panels critical load carrying capacity was determined for of glass panels designed in different thickness [**5**]. In generally, however, bolted connections are used connection type in glazing system [**6, 7**]. Bolted connections called as point supported concept [**8**] which usually require small metal components to be mechanically attached to holes in glass are commonly used a connection type in glazing systems. In this connection system, when load is transferred from bolts to the glass panel, the compressions contact force acts on the glass holes surface and causes stress concentrations. These stress concentrations can damage on the glass being a brittle material [**9**]. Hence, adhesively bonded technologies become an important role in glazing systems.

Technological improvements in adhesively bonded joints have been accompanied by an improvement in structural adhesives. As a result, the use of adhesively bonded joints has supplemented or replaced the use of traditional mechanical fasteners in composite and metallic structures. In these structures, adhesively bonded joints are in common use due to increased service life, design flexibility, reduced machining cost, improved load distribution, reduced complexity and provided uniform stress distribution [**10**]. Beyond these preferred features, recent advances in structural epoxies/adhesives have also expanded the temperature range over and they develop to provide structural integrity at high temperatures.

Thermal loading is undoubtedly a very important type of loading for many structural components that contain adhesive bonding system. The thermal strains in the joint members might cause serious stress, because the adhesive joints consist of materials with different thermal properties. For instance; adhesive joints used in aircraft need to low and high-temperatures, typically from -55°C (depending on altitude) to as much as 200°C or more [**11**]. It is known that high stress gradients exist near the edges of bonded joints due to mismatches in thermal expansion coefficients [**12**]. Besides, if the adhesive layer is not able to compensate for the difference in thermal strain, the bonded joint will be deformed or the adhesive joint may fail. In literature, some authors [**13-16**] are aware of the thermal effect and used it in their solutions. For example, Vinson and Zumstegs [**13**] studied at thermo-mechanical solution for adhesively bonded composite material joints. Adam et al. [**14**] focused on thermal loading in lap joints and the solutions were based FEM. Chen and Nelson [**15**] done a solution include thermal expansion and the materials were isotropic. Hart-Smith [**16**] provided a lap joint solution which included thermal loading and the worked focused on material non-linearity. Silva and Adams [**17**] investigated a mixed adhesive joint performance over a wide temperature range. Adhesively bonded joints carry a significant risk because of improper thermal buckling behaviours. Due to the increased use of bonded joints in glazing applications, the need for efficient-effective thermo-mechanical analysis and identifying the thermal bucking behaviours is great.

In literature, there is not much study about thermal buckling behaviour of adhesively bonded glass connections. Therefore, in this study, an adhesively bonded scarf joint was studied by using finite element method (FEM). Finite element model for the glass scarf joint having with isotropic (Aluminum, Steel) and anisotropic adherents (Boron-epoxy, Kevlar-epoxy and E glass-epoxy) were established. FEM analysis was also based on the usage of special surface to surface contact elements. The effects of the adherent properties on the critical buckling temperature were investigated. Adhesively bonded scarf joint mode shapes were also presented for the first five modes.

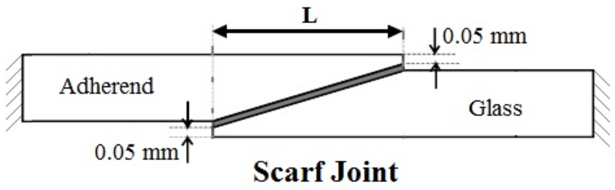

Fig. 1. Dimensions of scarf joint.

Materials and method

In this work, it is studied thermal buckling resulting from an elevated temperature on an adhesively bonded scarf joint fixed at both ends. The geometry of scarf joint used is as shown in **Fig. 1**. In the adhesively bonded scarf joint, overlap length, L is 12.7 mm and adherent/glass thickness are 3.18 mm, adhesive thickness is 0.254 mm and a small adherent tip thickness is also 0.05 mm. Temperature is 26°C when references temperature is 25°C.

Steel (St37) and Aluminum 2024 were used as isotropic adherents, and Loctite-Hysol 9464 [**18**], produced by Loctite, was used as the isotropic adhesive layer. The material properties of the isotropic adhesive layer can be seen in **Table 1**. The material properties of used glass and isotropic adherends are also shown in **Table 2**. Glass/epoxy, graphite/epoxy, and boron/epoxy were chosen for the anisotropic adherents in the adhesively bonded scarf joint model and material properties of these adherents can be seen in **Table 3**.

Table 1. Material properties of adhesive Loctite-Hysol 9464 [**18**].

Elastic modulus, E [GPa]	1.78
Poisson's ratio, ν	0.376
Coefficient of thermal expansion, α [K^{-1}]	4.33e-005

Table 2. Material properties of isotropic adherents.

Elastic properties	Steel (St 37)	Aluminum 2024	Glass
E [GPa]	210	73	70
ν	0.3	0.33	0.23
Coefficient of thermal expansion, α [K^{-1}]	1.2e-005	2.3e-005	9e-006

Table 3. Material properties of anisotropic adherents [**19, 20**]

Elastic properties	Glass/epoxy	Graphite/epoxy	Boron/epoxy
E_x [GPa]	38.60	127.50	207.00
E_y [GPa]	8.27	9.00	18.63
E_z [GPa]	8.27	4.80	18.63
$G_{xy} = G_{xz}$ [GPa]	4.14	4.80	4.50
G_{yz} [GPa]	4.00	2.55	3.45
$\nu_{xy} = \nu_{xz}$	0.25	0.28	0.27
ν_{yz}	0.27	0.41	0.35

The adhesively bonded scarf joint was modeled using two-dimensional Shell 181 elements and was divided into a finite number of elements satisfying the equilibrium and compatibility at each node. Also in the adhesive layer, a refined mesh was used in order to achieve the convergence and get more contact detection point. This was important in order to prevent any problems especially in the adhesively bonded joints. The joint model has contact pairs and contact elements were set the overlap between adhesive and adherents. Sliding is not permitted and debonding of two surfaces was not considered in present paper.

Results and discussion

Five types of adhesively bonded scarf joint were modeled such as steel/glass, aluminum/glass, boron-epoxy/glass, kevlar-epoxy/glass and e glass-epoxy/glass. These joint have one type adhesive layer assumed to be linear-elastic homogeneous isotropic. The influences of both isotropic adherents and anisotropic adherents on the buckling temperature were presented in **Fig. 2, Fig. 3** and **Fig. 4**. The buckling temperature values that correspond to the subsequent five modes of buckling were calculated for steel and aluminum adherents in **Fig. 2**. It should be remarked that the subsequent value of buckling temperature were not situated very close to one another. Since a unit thermal load was specified, the buckling temperature in the first mode was presented as the critical buckling temperature. The critical buckling temperature was obtained as 22.1°C for the adherent sample which was aluminum. This value was calculated 35.4°C for steel adherent sample. Thus, critical buckling temperature was increased 60.3% when one adherent glass was constant and the other adherent material changed aluminum to steel in scarf bonded structure.

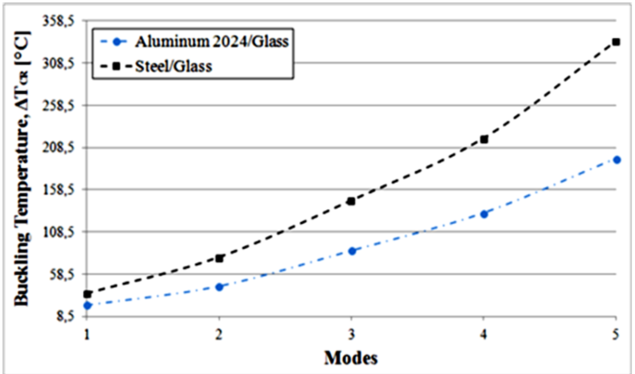

Fig. 2. Effects of the isotropic adherent material on the critical buckling temperature.

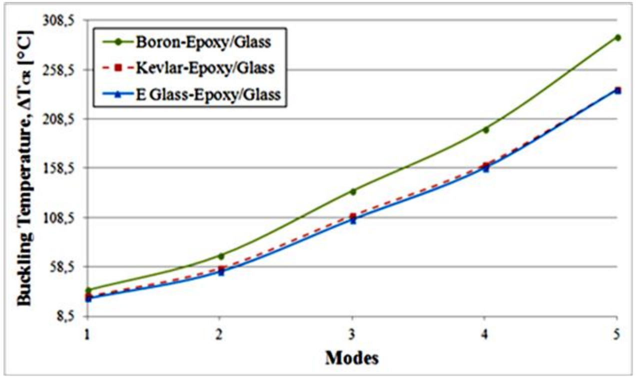

Fig. 3. Effects of the anisotropic adherent material on the critical buckling temperature.

In **Fig. 3**, the buckling temperatures of the whole anisotropic adherents can be clearly seen for each mode. Generally, the buckling temperature increases as the mode number increases. The buckling temperature increases approximately twice between mode 1 and mode 2 for anisotropic adherents. For instance, for boron-epoxy/glass joint the critical buckling temperature is 34.7°C in mode 1 and 69.8°C in mode 2. As seen in **Fig. 3**, when the comparison is done between boron-epoxy/glass and e glass-epoxy/glass in term of buckling temperature in mode 2, it is a differences account for 29.6%. This increment was calculated as 26.8%, 24.4% and 22.4% for mode 3, mode 4 and mode 5, respectively. In addition, when anisotropic adherents are compared, the maximum critical buckling temperature occurs for the boron-epoxy/glass joint. It should be also taken consider that the value of buckling temperatures for kevlar-epoxy/glass and e glass-epoxy/glass are situated very close each other.

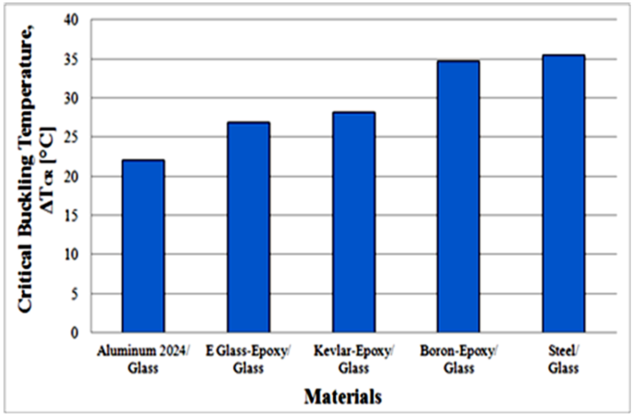

Fig. 4. Critical buckling temperatures according to all adherents materials.

In **Fig. 4**, the critical buckling temperatures of adhesively bonded scarf joint were compared according to the adherent material properties. The critical buckling temperature was obtained as 22.1°C for the adherent was aluminum The critical buckling temperature determined by e glass-epoxy/glass adherent 21.3% higher than that of aluminum sample. This increment was obtained as 27.5% for kevlar-epoxy/glass and 57.1% for boron-epoxy/glass. As for steel/glass joint, the critical buckling temperature was calculated as %60.3 higher than that of the aluminum joint.

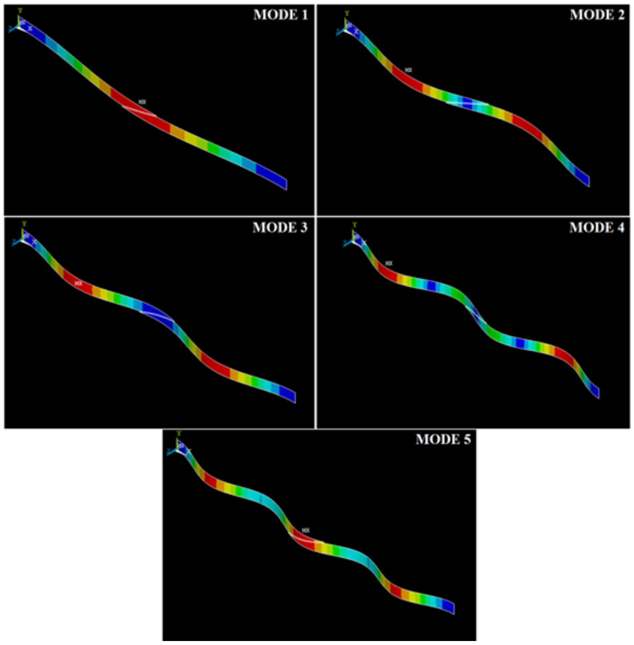

Fig. 5. Out of the plane deflection in aluminum/glass adhesively bonded joint on the first five modes.

The maximum out of the plane deflection of the aluminum/glass adhesively bonded scarf joint for the first five modes were presented in **Fig. 5**. In the mode 2 as is known in the adhesively joint two buckles were created. The one them was in z direction (positive buckle, red zone in mode 2) and the other was in - z direction (negative buckle in mode 2, red zone too). The mode shapes were similar for the other adherent materials.

Conclusion

In this study, the thermal buckling problem in scarf joint structures subjected thermal loading were investigated in detail by using finite element model. In the model glass adherent was adhesively bonded with isotropic/ anisotropic other adherent, this type of scarf joint structures uses as structural components in the field of glazing. Five types of scarf joint model were built up for thermal buckling analysis. These models were steel/glass, aluminum/glass, boron-epoxy/glass, kevlar-epoxy/glass and e glass-epoxy/glass. The obtained results reveal that critical buckling was effected differently by the adherent material types. The selecting of aluminum material adherent provide that the lowest thermal buckling temperature among both isotropic and anisotropic material adherents. Among the anisotropic adherent materials, the highest critical buckling temperature was also determined for the boron-epoxy/glass joint Besides, comparing the obtained results from the numerical investigation, it is seen that isotropic steel adherent have the highest buckling temperature in all adherent structures. The thermal buckling load type meet at adhesively bonded scarf joints when they used as structural manner in glazing applications [**1-3**] and transparent building [**4**]. The present comparative results can be useful for the thermal behavior of adhesively bonded scarf joints.

Supporting information

Supporting informations are available from VBRI Press.

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