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Numerical Study for Compressive Strength of Basalt Composite Sandwich Infill Panel

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Abstract**—**In this study, we investigated the buckling performance of basalt fiber reinforced polymer (BFRP) sandwich infill panels. Fiber Reinforced Polymer (FRP) is a major evolution for energy dissipation when used as infill material of frame structure, a basic Polymer Matrix Composite (PMC) infill wall system consists of two FRP laminates surrounding an infill of foam core. Furthermore, this type of component is for retrofitting and strengthening frame structure to withstand the seismic disaster. In-plane compression was considered in the numerical analysis with ABAQUS platform to determine the buckling failure load of BFRP infill panel system. The present result shows that the sandwich BFRP infill panel system has higher resistance to buckling failure than those of glass fiber reinforced polymer (GFRP) infill panel system, i.e. 16% increase in buckling resistance capacity.

Keywords**—**Basalt fiber reinforced polymer, buckling performance, FEM analysis, sandwich infill panel.

I. Introduction

FRAMED buildings with infilling walls have long been recognized as having considerable strength and stiffness subjected to lateral force. Uncertain and complex interactions of series of infilling frames have led real composite behavior of the structure to be considered as a statistically indeterminate problem. Extended as early as the 1950's and continue to date, available literature attempts to provide several efficient approaches in the field of analysis and design of infilled frames. Saneinejad and Hobb [1] and Jung and Myung [2] proposed a method of transforming the infilled frames into equivalent diagonal strut bracing frames. The studies stress that mutual interactions of the frame and infills panel play an important part in controlling the strength and stiffness of infilled frames. It was shown by Jung and Aref [3] that for equivalent diagonal strut model, diagonal stiffness and strength of the infill panels depend primarily on their dimensions, physical properties and length of contact with the surrounding structural frames. However, it should be noted that modeling of frame/infill contact lengths with exact mathematical solution is a complex issue involving several factors and high degree of uncertainty. Moreover, under seismic racking loads, the critical failure mode of frame, which depends on several factors, was owing to tension or shearing failure of the columns or beams. Additionally, it may occur in infilled frames as racking load increases if strength of frame is sufficient to prevent collapse by one of those modes. Aref and Jung [4] indicated that PMC materials could be utilized in a new efficient conceptual design for seismic retrofitting in existing facilities. Due to its high stiffness-to-weight and strength-to-weight ratios, the addition of PMC infill panels into existing structures will not significantly alter the weight of the structure while providing substantial structural enhancement.

Most commonly chosen PMC, i.e. carbon/glass/aramid fiber-reinforced polymer have been used in a number of notable demonstration projects, and extensive literature exists on their properties. It was recently mentioned in previous work by Sim and Jung [5] that the aforementioned reinforced polymer composites could enhance the performance of infill frames. Furthermore, the study has shown the optimal stacking sequence and length of contact to achieve the best PMC infill performance. However, between the different types of available fibers, Basalt fiber (BF) has been increasingly spreading as a new type reinforcing material of polymer composites with respect to its low cost, thermal insulation property, radiation/oxidation resistance and compression/shear strength. BF was first mentioned by Subramanian and Austin [6] who reported that BF could be applied to PMCs instead of glass fiber. Basalt's chemical composition is strongly related to glass. It is a mineral of volcanic origin and its most important components are SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, and FeO. It can be used between -200 and 600 ºC without the significant loss of mechanical properties due to its high molten temperature (between 1350 and 1700 ºC). Nevertheless, the disadvantages of BFs are related to their stiff and brittle nature. BFs have been comprehensively investigated as reinforcement of polypropylene (PP) matrix composites [7], [8]. Several studies mentioned the addition of resin, i.e. maleic anhydride (MA) [9] to the matrix composite in order to obtain adequate adhesion between the polymer matrix and avoid high sensitivity to fracture. In addition to the nature of PMC laminate skin, the research performed by Jung and Aref reveals that the failure of global buckling is dominant when designing the PMC infill panel under the influence of stacking sequence of its performance. Therefore, this study will investigate the performance of sandwich infill panel system with BF-reinforced polymer skin layer by means of numerical analysis with commercial finite element (FE) analysis platform ABAQUS [10]. The analysis focused on buckling response of PMC sandwich panel under diagonal compressive loads. Moreover, comparison with previous widely used fiber material will be briefly shown as a baseline for this study.

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II. Description and Mechanism of PMC Infill Panel

PMC infill wall system typically consisted of an infill of foam (core) surrounded by two FRP laminates (skin). This combination resulted in a strong, stiff, lightweight composite structures as can be seen in Fig. 1. In this case of study, fiber in laminate skin was BF, thus resulted in BFRP laminates as laminates skin; moreover, polystyrene was used as core. The overall dimension of the design is 2200 mm by 2400 mm with 6 mm skin thickness and 20 mm core which resulted in total thickness of 32 mm. Based on result from previous research, the design stacking sequences of skin laminate follows general orthotropic fiber-orientation with the following distribution $[45_5/\text{-}45_{10}/45_{10}/\text{-}45_{10}/45_5/$ core $/45_5/\text{-}45_{10}/45_{10}/\text{-}45_{10}/45_5]$. The subscript is the number of lamina in each fiber-orientation.

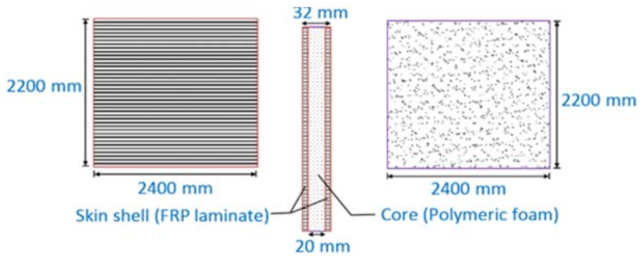


Fig. 1 Configuration and dimension of PMC infill

Additionally, the mechanical properties of core and BFRP skin were shown in Table I. To show the in-plane behavior of thin laminae, only four constants required. An analytical method was used to determine these constants based on the simplest method, rule of mixture, for the first modulus along the fiber direction. This method was based on the assumption of having the fiber (basalt) and the matrix (epoxy) deform in equal amounts along the fiber direction [11], [12]. This assumption is known to be very accurate, leading to an accurate estimation of the apparent elastic modulus E_1 as:

$$E_1 = E_f V_f + E_m V_m \tag{1}$$

where E_f is the fiber modulus, V_f is the fiber volume fraction, E_m is the matrix modulus, and $V_m = 1\text{-}V_f$.

The second modulus along the transverse direction can be determined by an assumption considering the stress σ_2 in the fiber and matrix. Elastic modulus E_2, can be estimated with a semi-empirical, Halpin-Tsai equation as [13]:

$$\frac{E_2}{E_m} = \frac{1+\xi\eta V_f}{1-\eta V_f} \tag{2}$$

$$\eta = \frac{E_f/E_m - 1}{E_f/E_m + \xi} \tag{3}$$

where ξ is a reinforcement parameter depending on the loading and boundary condition of the fiber geometry. Moreover, the suitable value of an empirical factor ξ, which has been observed to yield accurate results, is permitted to be taken as 1.

Poisson's ratio v_{12} may be determined by the rule of mixtures resulting from the previous two assumptions of having the fiber and the matrix deform in equal amounts along the fiber direction and having the transverse stress σ_2 = 0 [11]. These assumptions are known to be accurate, leading to an accurate estimation of the major Poisson's ratio v_{12} as:

$$\nu_{12} = \nu_f V_f + \nu_m V_m \tag{4}$$

where v_f is the fiber Poisson's ratio, and v_m is the matrix Poisson's ratio.

Shear modulus G_{12} is determined in the mechanics-of-materials approach using the assumption that the shearing stresses of the fiber and the matrix are identical. The determination of G_{12} could be obtained using the Halpin-Tsai equation as:

$$\frac{G_{12}}{G_m} = \frac{1+\xi\eta V_f}{1-\eta V_f} \tag{5}$$

$$\eta = \frac{G_f/G_m - 1}{G_f/G_m + \xi} \tag{6}$$

where ξ = 1 as in (3). Therefore, the four constants (E_1, E_2, v_{12} and G_{12}) could be determined and will be used in FE model of the infill panel system.

TABLE I
Mechanical Properties of Polystyrene and BFRP Lamina

Polystyrene		BFRP Lamina	
E [MPa]	120.0	E1 [GPa]	69.86
ν	0.33	E2 [GPa]	23.42
		ν12	0.24
		G12 [GPa]	8.83

III. Numerical Modeling and Analysis

Evaluation of buckling performance of infill panel was performed by developing FE model in ABAQUS platform; however, the model was simplified by modeling only the infill panel without the surrounding frames. Core layer was modeled with three-dimensional solid elements (C3D8); and skin plates were modeled by composite layup of BFRP lamina sheets and discretized with quadrilateral shell elements (S4R5). Moreover, to realize the in-plane compression design of the infill, triangular distributed compression loads were applied along the length of contact between columns and infills ($\alpha_c h'$), as demonstrated in Fig. 2. The contacts between beams and infills ($\alpha_b l'$) were modeled by constraining translational degrees of freedoms for both *Y*- and *Z*-direction and rotational degree of freedom for *Z*-direction. This length of contact was taken to be 500 mm.

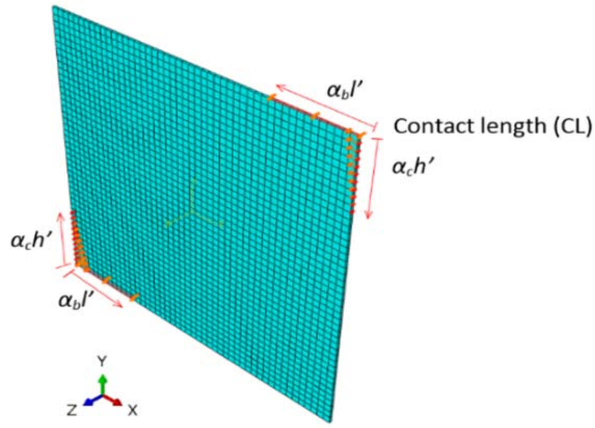
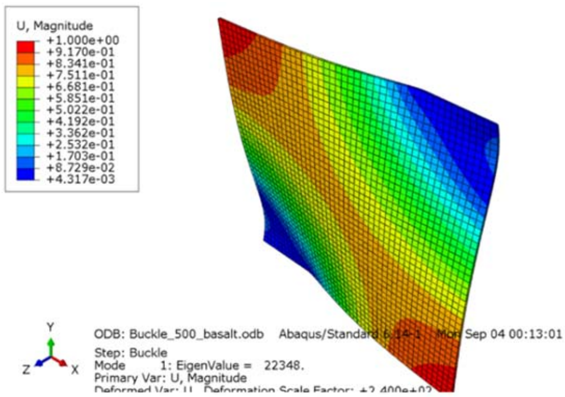


Fig. 2 FE model of BFRP infill panel

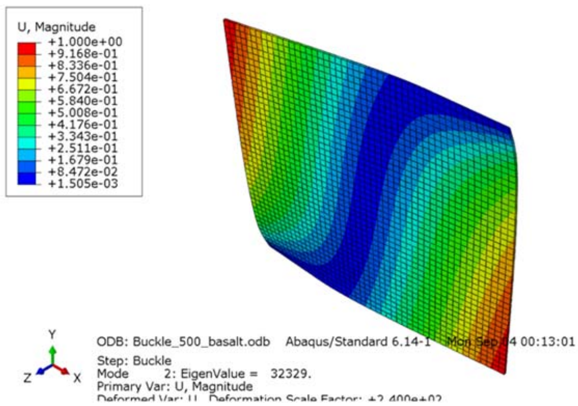
IV. Results and Discussions

Multiple modes of failure of infill can be obtained for this in-plane compression. As shown in Fig. 3, the most dominant mode of failure is Mode 1 with eigenvalue of 22348. From the eigenvalue of the dominated buckling mode shape, the critical load which causes the buckling failure could be determine by multiplying with the applied load. Therefore, the buckling of infill panel was expected when the in-plane compression load is above 123 kN.

(a)



(b)



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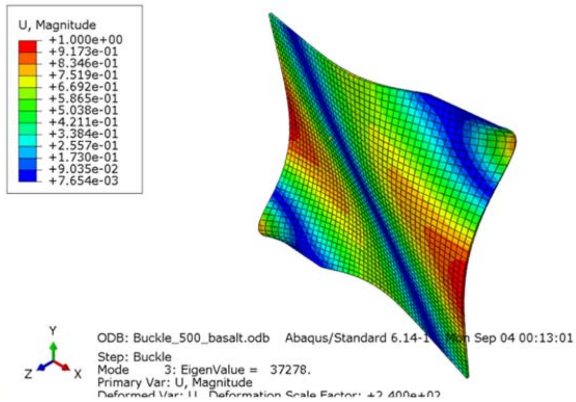

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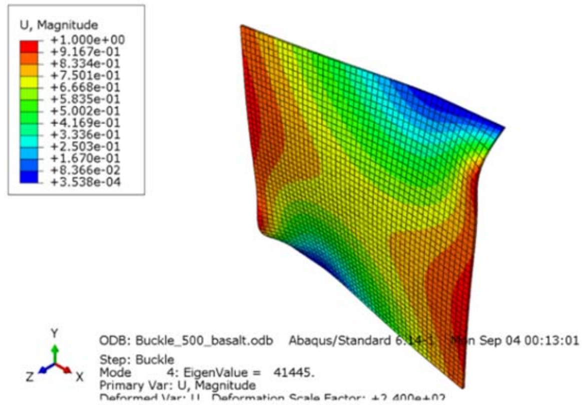

Fig. 3 Four failure modes of BFRP sandwich infill panel: (a) Mode 1, (b) Mode 2, (c) Mode 3 and (d) Mode 4

According to previous study [5], GFRP infill was expected to buckle when the diagonal compression loading is above 106 kN in ambient temperature. Additionally, the fraction of BF in BFRP in this study and the fraction of glass fiber-E in the previous study was chosen to have similar value. Thus, this result shows that the resistance to buckling failure of BFRP infill was better than GFRP infill, i.e. 16% in critical buckling load in BFRP infill panel system.

V. Conclusions

In this study, the estimation of buckling resistance of BFRP sandwich infill panel system was performed by means of FE modeling. The elastic properties of basalt/epoxy for BFRP were determined based on analytical method. Subsequently, a model of infill panel was developed in ABAQUS platform to determine the failure mode shape and eigenvalue of panel system. The results show that BFRP infill panel system has a higher resistance to buckling compare to GFRP infill panel system. There was 16% increase in the compression load for the BFRP infill to reach a failure due to buckling.

Some assumptions were made in this study; however, based on literature review, it was adequate. In future study, other parameters that affect the performance of infill panel will be considered, especially their polymeric nature.

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