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Buckling of Polymer Matrix Composite Sandwich Infill Panels Under Different Thermal Environment

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***Abstract*:** *This paper presents numerical analysis in terms of buckling resistance strength of polymer matrix composite (PMC) infill panels system under the influence of temperature on the foam core. Failure mode under in-plane compression is investigated by means of numerical analysis with ABAQUS platform. Parameters considered in this study are contact length and both the type of foam for core and the variation of its Young's Modulus under the thermal influence. Variation of temperature is considered in static cases and only applied to core. Indeed, it is shown that the effect of temperature on the panel system mechanical properties is significance. Moreover, the variations of temperature result in the decrements of the system strength. This is due to the polymeric nature of this material. Additionally, the contact length also displays the effect on performance of infill panel. Their significance factors are based on type of polymer for core. Hence, by comparing difference type of core material, the variation can be reducing.*

Keywords: *Foam core, Temperature dependent, Contact length, Buckling*

1. Introduction

Polymer Matrix Composite (PMC) materials are being used for new construction or retrofitting purpose due to their high strength to weight ratio. Structural frames with infill panels are typically providing an efficient and effective method for bracing building. The frame, while directly carrying some of the load, primarily serves to transfer and distributes the major part of the load to the infill panel. Therefore, the infill panel is able to resist substantially higher loads prior to finally collapsing by compressive failure.

The significance of infill walls, their contribution to enhancing strength, and stiffness of framed buildings subjected to lateral forces have been addressed. Many researchers have attempted to develop simplified methods for analysis and design these infill frames, when subjected to in-plane forces. The works performed by Jung & Aref [1,4], present the compressive instability of a solid PMC infill panel and discuss the influence of properties of FRP and loading conditions by the concept of diagonal sandwich strut models. It was shown that the failure of global buckling was dominant, when designing the PMC infill panel. The results showed the significance of the fibre reinforcement polymer (FRP) skin and its design stacking sequence. The effect of temperature, however, has never been considered for both FRP skin and foam core. The thermal properties of polymeric materials are important to the function of components and assemblies that will operate in cold or warm environments.

Consequently, this paper presents numerical analysis with respect to the buckling response of PMC infill panels system under the influence of temperature on the polymeric core and then compares the buckling strength of the system, when difference types of polymer foams are applying for core.

2. Design and Performance Mechanism of PMC Infill Wall

PMC infill panel is introduced as a panel material with increased lateral resistance; it employs a sandwich design concept to reduce weight, sound and vibration as well as to improve the structural rigidity of the panel. This design procedure must specify many design variables of both FRP skin laminate and core. Such variables include the thickness, fibre orientation, stacking sequence of FRP plies, and geometrical parameters. In addition, FRP sandwich structures expose to very high structural efficiency (ratios of strength or stiffness to weight). In order to obtain the high performance at low cost, the thinly spaced core-shell laminates are designed to provide bending rigidity, and the space between the laminates is filled with polymeric sheet foam.

As the racking load is increased on infill frame structures, failure occurs eventually at either the frame or the infill panel. The critical modes of frame failure are tension in the column or shearing of the column or beams. However, if frame's strength is sufficient to prevent its collapse by one of these modes, the increasing racking load eventually produces compressive failure in the infill panel. The failure mode of sandwich PMC infill panel can be generally classified into three categories: (1) instabilities, such as overall buckling, (2) face wrinkling, caused by insufficient plate- or face-bending stiffness and core elastic properties, and (3) fracture, either of the face sheets under compression or of the core under transverse shear.

The combined behaviour of a series of infill frame structures is a complex, statically indeterminate problem. The mutual interactions of the frame and infill panel play an important part in controlling the stiffness and strength of the infill frame. For diagonally equivalent strut models, it has been shown by previous research [4] that the diagonal stiffness and strength of the infill panel depends primarily on its dimensions, physical properties, and length of contact with the surrounding frame. Using the length of contact between the infill and frame, it is possible to make a series of stress analyses for panels loaded diagonally by compressive forces with calculated distributions of interaction over different lengths of contact against the columns and beams.

3. Configuration of PMC Infill Wall and Effect of Temperature

The configuration of the panel system is shown in Fig. 1 with the total thickness of 64 mm, consisted of two 12 mm FRP skins and 40 mm core. The geometry and properties of GFRP lamina at ambient temperature are shown in TABLE . The optimal design parameters with respect to fibre orientation of the FRP laminate skin are $[0_6/30_8/45_4/60_0/90_5/–60_0/–45_4/–30_8/0_5]_S$ with total thickness of 12 mm. The selected optimum stacking sequences were determined by considering the stiffness as well as the applied loading condition of each laminate [1].

TABLE I: Geometry of Panel and Mechanical Properties of GFRP Lamina at Ambient Temperature

Geometry of panel	Width	2400 mm
	Height	2200 mm
	Thickness	12 mm
Property of lamina sheet	E_1	55 GPa
	E_2	16 GPa
	ν_{12}	0.26
	G_{12}	7.6 GPa

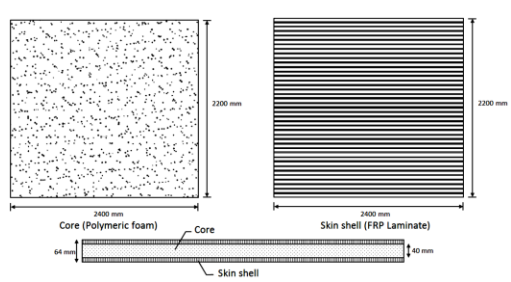

Fig. 1: Configuration of the PMC infill panel system.

For this study, the PMC infill panel uses two types of closed-cell polymeric foam for the cores, which are Polyurethane (PU) and Polybutylene terephthalate (PBT). Tobushi [5] and Padini [7] have shown that the increase of temperature causes the reduction of characteristic parameter, such as elastic modulus, yield stress and Poisson's ratio of the polymer material, thus affects those of the polymeric foam. Gibson and Ashby [2] derived the prediction of relative Young's Modulus as function of relative density of foam as shown in equation (1) below:

$$\frac{E^*}{E_s} \approx \phi^2 \left(\frac{\rho^*}{\rho_s}\right)^2 + (1-\phi)\frac{\rho^*}{\rho_s} + \frac{\rho_o(1-2\nu^*)}{E_s(1-\rho^*/\rho_s)} \tag{1}$$

Where, the superscript * is effective properties of polymer foam and subscript "*s*" refers to the properties of the solid polymer. The value of $\nu^* \approx \frac{1}{3}$.

The properties of the two types of foam at difference cases of temperature are shown in

TABLE , accompanied by Fig. 2 which shows the evolution of Young's Modulus as function of temperature. In this figure not only that it highlights the important properties of each foam under effect of temperature, yet the evolution of these curves will also serve as an explanation to the development of buckling resistance curves that will later determine. Since elastic modulus decrease brutally above its glass transition temperature, referred herein as T_g (the point at which a material goes from a hard brittle state to a soft rubbery state), to get a proper comparison the slope calculated with linear regression will consider only the data which is below T_g. Therefore, it is observed that with the same range of temperature, the slope of PU (–0.161) is smaller than that of PBT (–1.011). Hence, the temperature has more effect on the property of PBT foam in contrast to how it affects PU.

TABLE II: The Mechanical Properties of the Foam at Temperature –20˚C to 60˚C

Temperature [˚C]		–20	0	20	40	60
Polyurethane	E [MPa]	56.08	53.95	48.69	48.01	40.72
	ν	0.334	0.334	0.334	0.334	0.334
Polybutylene	E [MPa]	111.31	103.84	95.7	65.97	30.96
	ν	0.333	0.334	0.333	0.334	0.334

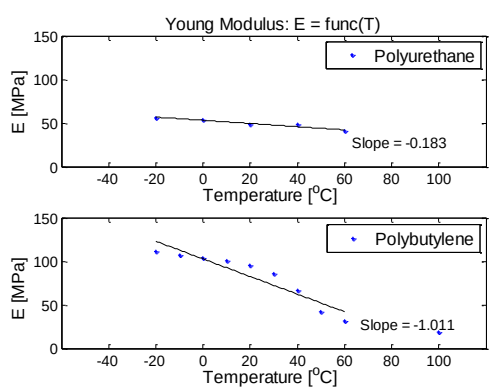

Fig. 2: Young's Modulus (E) of Polyurethane (PU) and Polybutylene (PBT) in function of temperature T (˚C).

In this study, the variation of temperature is assumed to affect only the foam core of the panel and neglect the temperature dependence of skin and bonding contact between layers. The effect of temperature is static case without temperature gradient. This research will serve as a framework for a more detail consideration of temperature effect which will be done in future.

4. Numerical Analysis of the PMC Infill System

Three-dimensional static analyses of the PMC Sandwich panel were conduct in ABAQUS [6]. In the Finite Element (FE) model of the PMC infill frame structure, only the PMC infill panel was modelled, not the surrounding frames. The core sheet layer was modelled with three-dimensional solid elements (C3D8). The skin plates were modelled by composite layup of GFRP lamina sheet and discretized with quadrilateral shell elements (S4R5). A tie constraint was introduced between the nodes of the shell elements and the solid elements.

Material properties used for this analysis are given in TABLE for FRP skin laminate and

TABLE for the core. Following the assumption above only the variation of mechanical properties of core is being considered.

The contact between beams and infill was modelled by constraining both translational degrees of freedoms for Y- and Z-direction and rotational degree of freedom for Z-direction along the contact location of the top and bottom beams, as shown in Fig. 3. Triangularly distributed compression load was applied along the length of contact area against the columns.

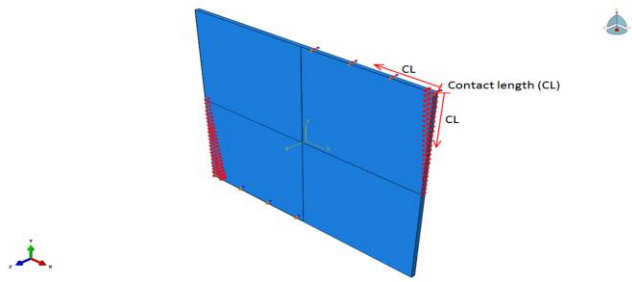

Fig. 3: FE model and boundary condition of the panel in ABAQUS.

5. Result and Discussions

5.1. Failure mode of panel system

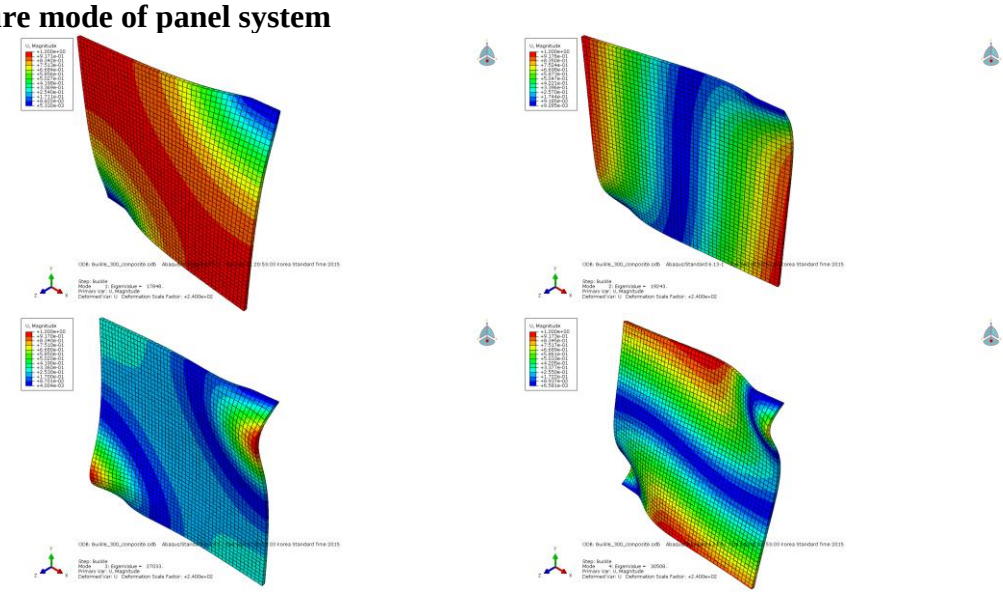

Fig. 4: Mode of failure of PMC infill panel system with contact length 300 mm.

Four possible buckling modes of panel system with contact length equal to 300 mm are shown in Fig. 4. Eigenvalues, also known as load multipliers, are extracted and the lowest value is the most important. The buckling mode shapes, also known as eigenvectors, are often the most useful outcome, since they predict the likely failure mode of the structure. By multiply the lowest eigenvalue dominated buckling mode, with the load

applied, the most likely load to cause the failure of the structure is obtained from the buckling resistance load of the panel system.

5.2. Effect of temperature variation

Fig. 5 illustrates the effect of core material on buckling resistance of entire panel system under different range of temperature. As the temperature increases, the buckling resistance decreases. In this section, evolution of buckling resistance as a function of temperature for two different foam cores: Polybutylene (PBT) and Polyurethane (PU) are discussed. At one value of contact length of 500mm, the decrement percentage of buckling resistance per one degree Celsius shown in Fig. 5 is found to evolve in the same trend with Young's Modulus curves Fig. 2: for Polyurethane at temperature ranging from –60˚C to 60˚C, buckling strength decreases linearly with a slope of –0.239. Furthermore, over this considered range of temperature, the decrement percentage of buckling resistance per one degree Celsius is found to be –0.17%/˚C. Finally, over temperature ranging from –20˚C to 60˚C, Polybutylene exhibits a similar behaviour with deeper slope of –2.40 and a higher decrement percentage of –2.01%/˚C.

This behaviour of the entire panel can be attributed to the effect of property of foam core since the decrements of buckling resistance have been observed to be in the same manner (PU<PBT) as in Young's Modulus curves under the variation of temperature. As a result, a highly sensitive of foam core property in response to the variation of temperature leads to a highly sensitive of variation of buckling resistance of the entire panel.

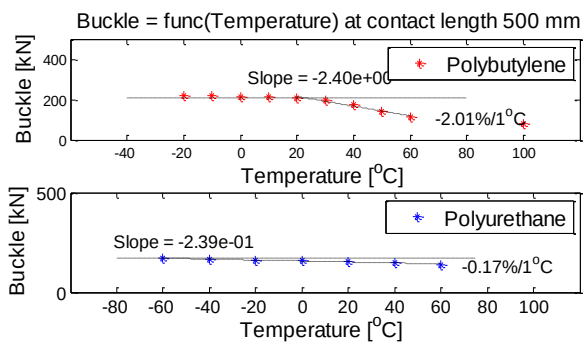

Fig. 5: Buckling resistance in function of temperature of a) Polyurethane and b) Polybutylene core (contact length 500 mm).

5.3. Effect of temperature variation regarding contact length

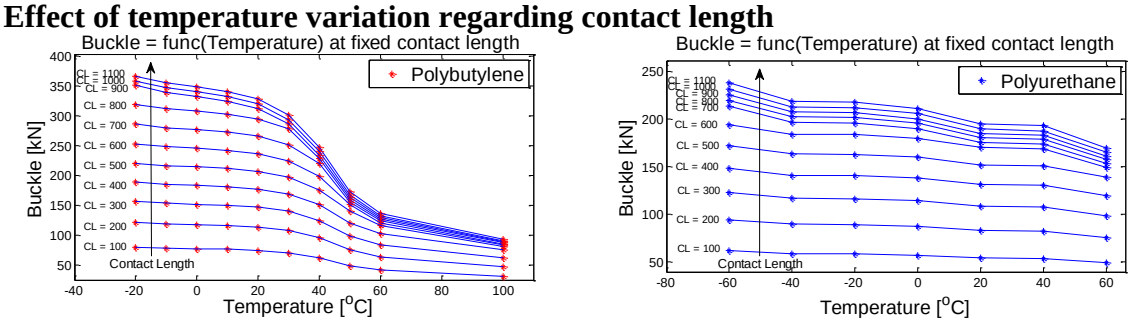

Fig. 6: Buckling resistance in function of temperature for each contact length (CL from 100 mm to 1100 mm with a discrete step of 100 mm).

Fig. 6 illustrates buckling resistance curves of panel system with different contact lengths responding to the variation of temperature. Over a chosen range of contact length from 100 mm to 1100 mm, Fig. 6a and Fig. 6b corresponds to the evolution of buckling resistance in each case of foam core, Polybutylene (PBT) and Polyurethane (PU), respectively. In this section, behaviours in different phases of foam core are discussed.

As already mentioned, buckling resistance decreases as temperature increases at a fixed contact length. Also, as shown in Fig. 6, the curve corresponding to various contact length still produces the same behaviour

responding to the increase of temperature. It is observed that there occurs the downward displacement of each curve as panel's contact length decreases. This indicates that buckling resistance decreases proportionally to its contact length. Progressively, when reaching a certain value of temperature: T = 100˚C for PBT, all curves from every conditions of contact converges to a common value below 100kN. This behaviour is attributed to the existence of transformation to another phase of the foam core as the temperature goes beyond its glass transition temperature.

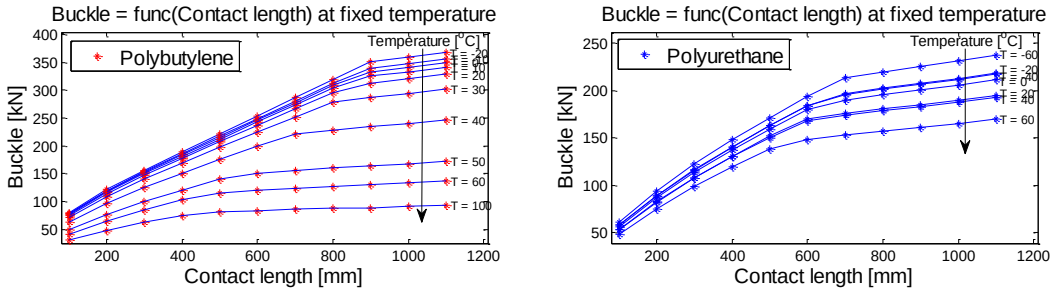

Fig. 7: Buckling resistance at difference contact length for difference temperature: a) PBT, and b) PU.

In another perspective, Fig. 7 gives an important equivalent representation of Fig. 6. It is obvious that in each case, buckling strength of the panel exhibits two different regimes mentioned in Fig. 6. The first regime is found around the upper part of the curves where the temperatures are below glass transition temperature (T_g). In Fig. 7, we could clearly see that there is a threshold value for buckling resistance at certain value of contact length (900 mm for PBT and 700 mm for PU), strength linearly increase and suddenly decrease its slope after the critical contact length. As the temperature increase, buckling curves shifts downward inversely proportional to the temperature. This leads to a division to another regime where buckling strength becomes constant regardless of the variation of contact length used.

The effect of contact length on the strength of panel can be seen in Fig. 7 that beyond glass transition temperature (T_g), the increment is practically linear for all contact length. This result gives an interesting property of the panels' strength under effects of three different variables: types of foam core, effect of temperature and effect of contact lengths which are an indispensable additional criterion to help decide, which foam core to be chosen in different condition of usage such as different contact length or in different environment with a different range of variation of temperature.

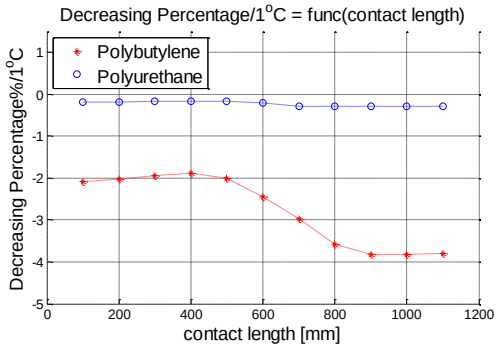

Fig. 8: Comparison of decreasing percentage of buckling resistance for each foam material.

More quantitatively, the decrement percentage of buckling resistance of panel system over the considered range of contact length in the region below glass transition temperature is summarized in Fig. 8. The curves were constructed from Fig. 6 and Fig. 7. In this figure, the comparison of decrement percentage of buckling resistance in each case of the foam core is described. Panels whose foam core is PU, have decrements' percentage less than 0.3%/˚C with small variation over considered range of various contact length, whereas panel whose foam core is PBT decreases sharply from a linear of 2%/˚C before CL = 400 mm and constantly approaches the decrements of 4%/˚C, when reach threshold contact length, which is greater than 900 mm.

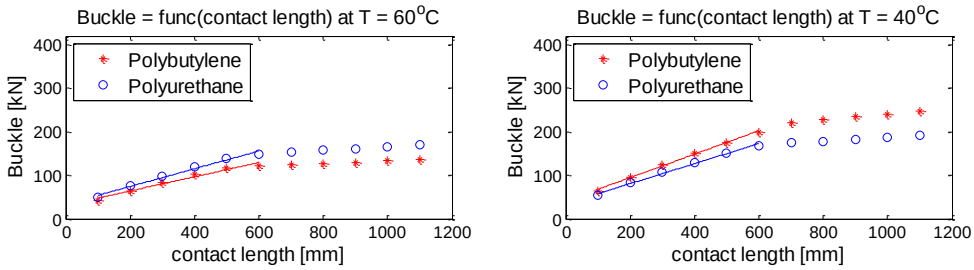

Fig. 9: Comparison of buckling resistance at a) 40˚C and b) 60˚C.

Represent as an example, Fig. 9, from 40˚C to 60˚C, polybutylene curve shifts the buckling curve from above to below Polyurethane. With this figure, it's also agreed with the discussion above, polybutylene is highly sensitive to changing of temperature. Not only as a confirmation to sensitivity of Polybutylene yet this figure also gives an example for the best choice of foam core in this particular condition of test. Out of these two foam cores studied, Polyurethane is considered to be the best choice of material for the core of the panel system.

6. Conclusions

It is a fact that, the entire PMC-infill panel system is thermal dependence. From this study, it is noted that certain foam core result in less variation of the mechanical properties of the panel system. In general, they show small variation of buckling resistance in term of temperature variation. This is due to the fact that their elastic modules are less sensitive to thermal influence. Hence, this result demonstrate the significant effect of type of foam on the behaviour of the entire panel system which in turn can be utilize in selecting the type of foam for core. Additionally, the structural parameter, contact length, also affects the performance of the infill panel. But, there are threshold at certain value of contact length which end the variation of the buckling resistance in function of temperature.

However, this study only serve as a ground work for further study with different foam materials. The fact that, in this study the temperature variation has been considered static case and affected only the core layer, showing the deficiency of the results obtain. In particular, the results developed the trend, which will profit for future study where the effect of temperature on the skin layer and binding from one layer to another, will be considered.

7. Acknowledgements

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