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Buckling Resistance of GFRP Sandwich Infill Panels with Different Cores under Increased Temperatures

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***Abstract*—**This paper presents numerical analysis in terms of buckling resistance of GFRP sandwich infill panels system under the influence of increased temperature on the foam core. Failure mode under in-plane compression is studied 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 module elastic under the thermal influence. Increment of temperature is considered in static cases and only applied to core. Indeed, it is proven that the effect of temperature alters the mechanical properties of the entire panel system. Moreover, the rises of temperature result in a decrease in strength of the panel. 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. Therefore, by comparing difference type of core material, the variation can be reducing.

***Keywords*—**Buckling, contact length, foam core, temperature dependent.

I. Introduction

RECENTLY, Polymer Matrix Composite (PMC) materials have received considerable attention because of the increasing demand for their high strength to weight ratio. In practical applications, they have been proposed for new construction or retrofitting purpose such as columns, beams, and unreinforced masonry walls. In addition, 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.

Previous scholars have addressed the significance of infill walls, their contribution to enhancing strength, and stiffness of framed buildings subjected to lateral forces. Until now, 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 [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. Results from this study reveal that the failure of global buckling was dominant, when designing the PMC infill panel. The results highlighted the key roles of the fiber reinforcement polymer (FRP) skin and its design stacking sequence. However, the effect of temperature 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 different environments. In earlier study [11], the comparison was made between two foams over a wide range of contact length and temperature; it shows the threshold value of buckling resistance strength at certain length of contact. Therefore, the current study extents the 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 three difference types of polymer foams are applied. We critically observe in details inside a new range of contact length with temperature variation under glass transition temperature of the polymer foams for the reason that beyond glass transition temperature the property of polymer material will change dramatically.

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II. 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, fiber 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 strength of frame 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 behavior of a series of infill frame structures is a complex, statically indeterminate problem [8]. 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.

III. 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 GFRP skins and 40 mm core. The geometry and properties of GFRP lamina at ambient temperature are shown in Table I [7]. The optimal design parameters with respect to fiber orientation of the GFRP laminate skin are $[0_6/30_8/45_4/90_5/{-45}_4/{-30}_8/0_5]_S$ 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], [3].

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

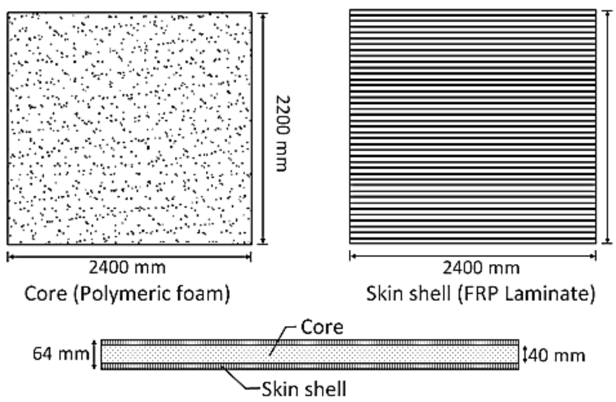


Fig. 1 Configuration of the PMC infill panel system

For this study, the PMC infill panel uses three types of closed-cell polymeric foam for the cores, which are Polyurethane (PU), Polybutylene terephthalate (PBT), and Polystyrene (PS). Tobushi [10], Padini [5], and Mott [6] 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 solid 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 (1):

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

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

TABLE II
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
Polystyrene	E [MPa]	130.7	125.4	120.0	113.9	110.9
	ν	0.333	0.333	0.333	0.333	0.333

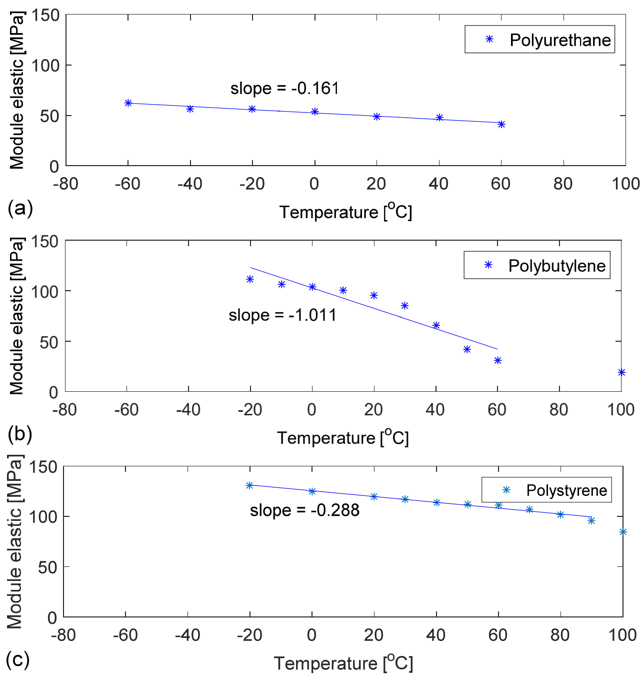


Fig. 2 Module elastic (E) in function of temperature (T) of (a) Polyurethane (PU), (b) Polybutylene (PBT), and (c) Polystyrene (PS)

The properties of the three types of foam at difference cases of temperature are shown in Table II, accompanied by Fig. 2 which shows the evolution of Young's Modulus as function of temperature. In Fig. 2, 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 in the following order PU, PS, and PBT with the value –0.161, –0.288, and –0.1.011, respectively. Hence, the temperature has more effect on the property of PBT foam in contrast to how it affects PU.

In this study, the variation of temperature is assumed to affect only the foam core of the panel and neglect the temperature dependency 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 with gradient effect which will be done in future.

IV. Numerical Analysis of the PMC Infill System

Three-dimensional static analyses of the PMC Sandwich panel were conduct in ABAQUS [9]. 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 I for GFRP skin laminate and Table II for the core. Following the assumption of temperature affect just the foam core, 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.

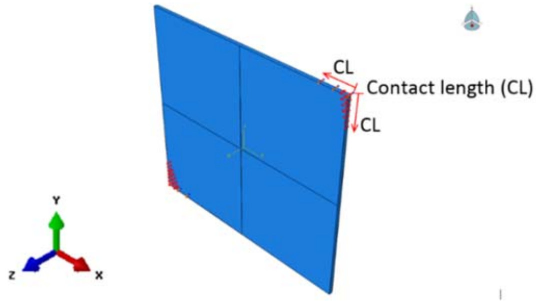


Fig. 3 FE model and boundary condition of the panel in ABAQUS

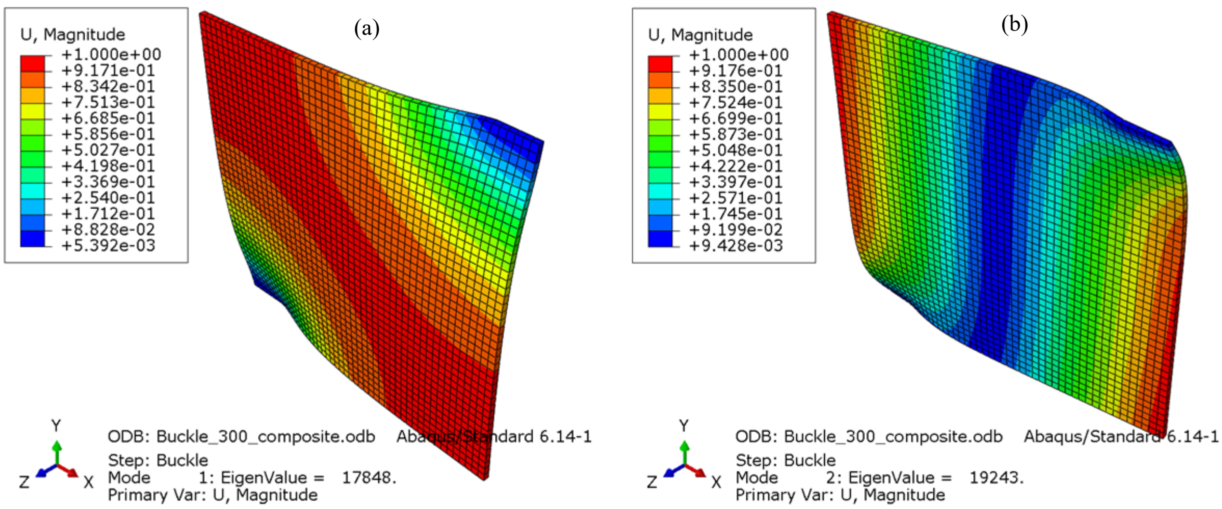
V. Results and Discussions

A. Failure Mode of Panel System

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, which is the 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.

B. 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 the three different foam cores: Polybutylene (PBT), Polyurethane (PU), and Polystyrene (PS) are discussed. At one value of contact length of 300 mm, 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.



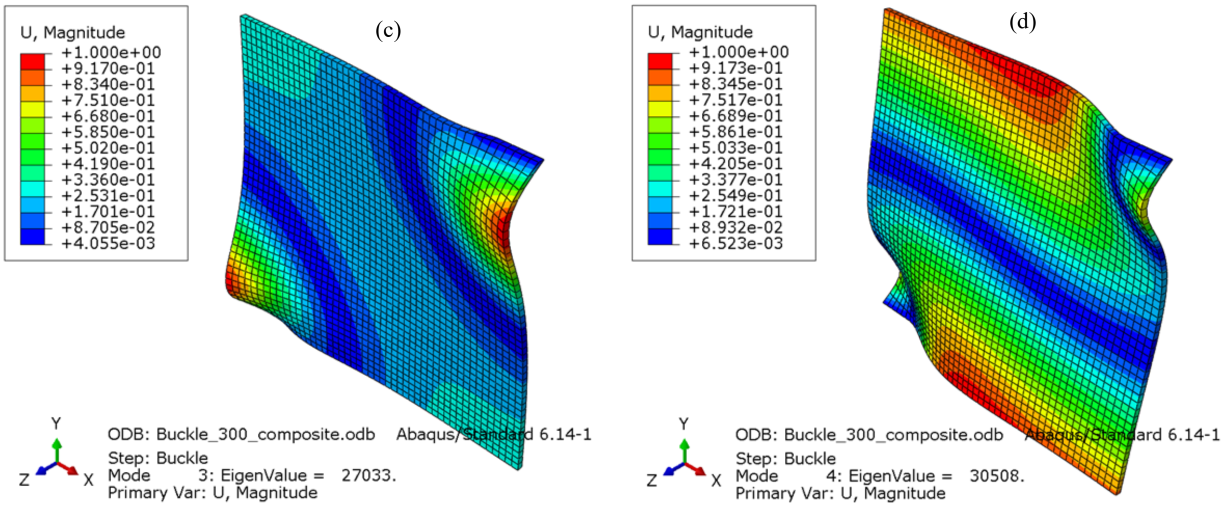


Fig. 4 Modes of failure of PMC infill panel system (a) Mode 1, (b) Mode 2, (c) Mode 3, and (d) Mode 4

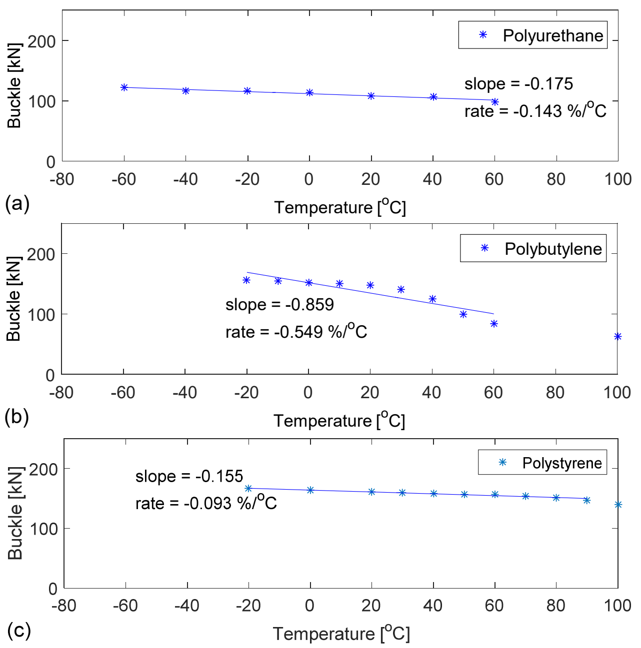


Fig. 5 Buckling resistance in function of temperature at contact length 300 mm for (a) Polyurethane (PU), (b) Polybutylene (PBT), and (c) Polystyrene (PS)

With Polyurethane as core material, buckling strength of panel decreases linearly with a slope of –0.175. Furthermore, over this considered range of temperature, the decrement percentage of buckling resistance per one degree Celsius is found to be –0.143%/˚C. In the case of Polybutylene as core material, panel's buckling strength exhibits a similar behavior but with a higher slope of –0.859 and the decrements percentage of buckling resistance found to be –0.549%//˚C. Lastly, while using Polystyrene as core material, buckling strength of panel, decreases linearly with a slope of –0.155 and a decrement percentage of –0.093%/˚C. The sense of decrement percentage is normalizing value of buckling resistance decrement rate per 1˚C over the maximum buckling resistance. This behavior 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 (PS<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. 6 illustrated buckling resistance of panel system in function of contact lengths and the temperature for panel system when using three different types material for core. Over a chosen range of contact length from 100mm to 500mm, the evolution of buckling resistance in each case of foam core, Polyurethane (PU), Polybutylene (PBT), and Polystyrene (PS), are presented from top to bottom, respectively. As prior observed, buckling resistance decreases as temperature increases at a fixed contact length. In addition, as shown in Fig. 6, the curve corresponding to various contact length still produces the same behavior responding to the increase of temperature. It is pragmatic that there occurs the downward displacement of surface as panel's contact length decreases. This indicates that buckling resistance decreases proportionally to its contact length and it is also obvious that the decrement is linearly. Therefore, below T_g, the behavior of buckling strength is linear in term of both temperature and contact length. 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. 7. The curves were constructed by calculating all the decrement percentage (rate) from Fig. 6 in the same manner as Fig. 5. In Fig. 7, the comparison of decrement percentage of buckling resistance in each case of the foam core is described. Panels whose foam core is PU and PS, have decrements' percentage less than 0.2%/˚C with small variation over considered range of various contact length, whereas panel whose foam core is PBT have the variation three times of the other two which is nearly 0.6%/˚C. This result suggests that Polystyrene performs the best as material for core when the variation of temperature is considered during performance of

GFRP infill panel under compression load.

C. Effect of Temperature Variation Regarding Contact Length

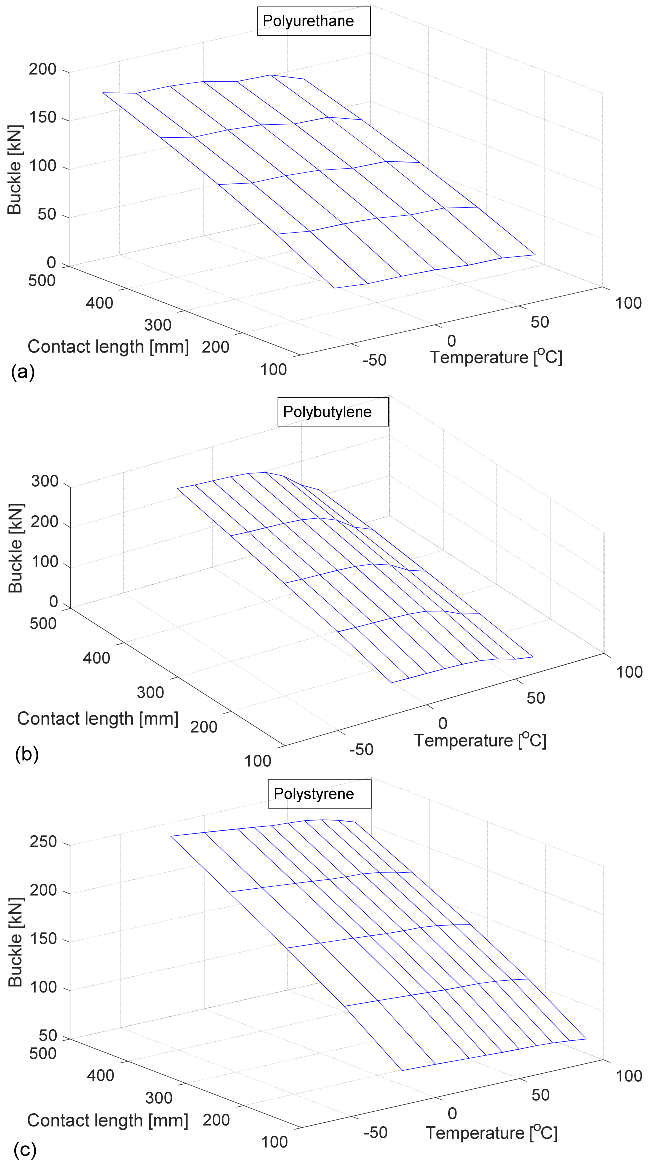


Fig. 6 Buckling resistance in function of temperature and contact length for (a) Polyurethane (PU), (b) Polybutylene (PBT), and (c) Polystyrene (PS)

VI. Conclusions

It is a fact that, the entire PMC-infill panel system is thermal dependent. From this study, it is noted that certain foam core results in larger variation of the mechanical properties of the panel system such that of Polybutylene compare to Polyurethane and Polystyrene. It shows large variation of buckling resistance in term of temperature variation. This is due to the fact that their elastic modules are more sensitive to thermal influence. Hence, this result establishes the notion of significant effect of type of foam on the behavior of the entire panel system which in turn can be utilized in selecting the type of polymer for core. Furthermore, the structural parameter, contact length, also affects the performance of the infill panel, nevertheless this is expected because the reduced of strut width of the diagonally equivalent strut models. However, the significance factor of thermal effect on the core is yet to be determined, it requires the comparison with the results of thermal effect on skin to be truly determined which one has higher impact. This study only serves as groundwork for further study with other parameters. 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.

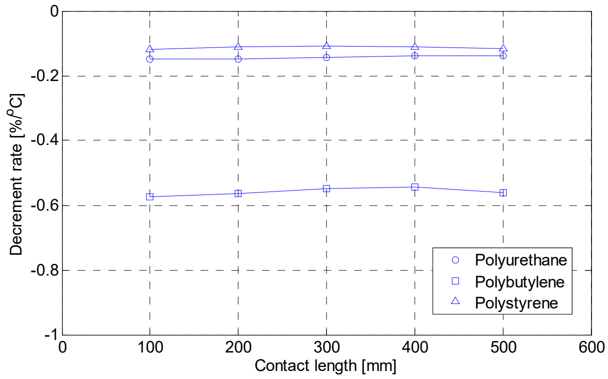


Fig. 7 Comparison of decreasing percentage of buckling resistance for each foam material

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