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Thermal Instability of A Polymer Panel Reinforced with Glass Particulates

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Abstract
Water and oil reservoirs are commonly made from polymers. To enhance their mechanical strength, the technique of incorporating short glass particulates into the polymers is employed. This method improves the overall reliability of the reservoirs. The objective of this study is to analyze the thermal instability that occurs during the buckling of panels in these reservoirs. Previous research has shown that the addition of short glass particulates can negatively impact thermal buckling. In the first stage of this study, polymers will be mixed with 10% and 20% short glass particulates, and a calculation script will be developed to determine the thermal buckling behavior.

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1.Introduction

Polymer reservoirs are commonly used for the storage of water, oils, and petroleum products such as gasoline and diesel. These reservoirs can have cylindrical, ellipsoidal, square, or rectangular shapes. Like all structures, polymer reservoirs are subjected to mechanical and thermal loads. This study specifically focuses on the thermal loads applied to square or rectangular walls to assess the variation in the critical buckling temperature. Youssef Hilali et al. (2025) studied the thermal buckling and post-buckling behavior of functionally graded material (FGM) plates using a higher-order theory, demonstrating accurate predictions of structural responses (Hilali et al., 2025). Guangjie Han et al. (2025) investigated the buckling and post-buckling behavior of FGM plates reinforced with graphene nanoplatelets, showing that graphene significantly enhances the stiffness of the plates (Han et al., 2025). Han Zhang et al. (2019) conducted a comprehensive study on the buckling behavior of marine pipes, providing an overview of stability, buckling, and free vibration analysis of FGM structures (Zhang et al., 2019). Irina Vikhareva et al. (2021) examined biodegradable polymer materials modified with microstructured titanium phosphate under thermal loading and concluded that the modified polymers outperform conventional polymers (Vikhareva et al., 2021). Joris Doumouro et al. (2021) quantitatively analyzed heat transfer between particulates at the micrometer scale, offering precise measurements of thermal contact resistance (Doumouro et al., 2021). Ike (2025) conducted a study on plate buckling using the Galerkin method (Ike, 2025), and also investigated the buckling of Euler-Bernoulli beams resting on elastic foundations (Ike, 2024a). Further, Ike (2024b) analyzed beam buckling using the Ritz variational method with two foundation parameters (Ike, 2024b). Turan et al. (2024) studied the buckling of orthotropic FGM plates considering shear deformation effects (Turan, 2024). Finally, Turan et al. (2025) analyzed the lateral-torsional stability and various buckling behaviors of structural elements under uniform mechanical or thermal loading, taking shear deformation into account (Turan et al., 2025). Numerous studies have focused on improving concrete properties. Harrat et al. (2021) examined the agglomeration of nanosilica in concrete applied to beams, highlighting its influence on structural performance (Harrat et al., 2021). Chatbi et al. (2022) evaluated the effect of nanosilica in slabs resting on elastic foundations, demonstrating enhanced bending behavior (Chatbi et al., 2022). Benfrid et al. (2023) investigated the thermomechanical performance of panels incorporating glass powder, providing a detailed evaluation of limitations and performance (Benfrid et al., 2023). Elhennani et al. (2023) analyzed beams reinforced with three types of nanoparticles, considering buckling and free vibration on multi-parameter elastic foundations (Elhennani et al., 2023). Kechir et al. (2024) conducted a study on beams with nano-sized iron oxide particles, showing improved mechanical performance and bending behavior (Kechir et al., 2024). Several researchers have studied metal-based fibers. Błaszczyński and Przybylska-Fałek (2015) demonstrated that the addition of steel fibers increases the critical compression load (Błaszczyński and Przybylska-Fałek, 2015). Khaloo and Afshari (2005) affirmed that fiber-reinforced slabs exhibit improved deflection resistance (Khaloo and Afshari, 2005). Mohod (2012) noted a slight reduction in workability but a significant increase in mechanical strengths (Mohod, 2012). Other studies, such as those by Mujalli et al. (2022), indicated approximately a 2% improvement in the performance of steel fiber-reinforced concrete compared to conventional concrete (Mujalli et al., 2022).

This study aims to address two key issues. The first is the homogenization of polymers with glass particulates at 10% and 20%. The second is a thermal buckling case study using the First-Order Shear Deformation Theory (FSDT) for plates.

2. Material and Method

2.1. Homogenization

For the homogenization process, the mixing method was examined to determine the thermo-mechanical properties of polymers mixed with glass particulates. For the polymers, the elastic modulus is 2 GPa, the Poisson's ratio is 0.2, and the thermal expansion coefficient is 80 × 10^{-6} /°C. For glass particulates, the elastic modulus is 70 GPa, the Poisson's ratio is 0.16, and the thermal expansion coefficient is 7 × 10^{-6} /°C (Chawla, 2000; Mallick, 2000). A decrease in both mechanical and thermal properties is observed with the incorporation of glass particulates.

$$X_f = X_c * V_c + X_s * V_s$$

Table 1. The thermomechanical properties.

Vf (%)	The elastic modulus (GPa)	The thermal expansion coefficient (10^{-6} /°C)	The Poisson's ratio
0	2	80.1	0.22
10	8.9	72.9	0.2
20	15.7	65.6	0.19

2.2. Study of thermal buckling

En utilisant la référence (Sayyad and Ghugal, 2014), créez un script de calcul capable de calculer le flambage thermique.

$$NO := \int_{-\frac{h}{2}}^{\frac{h}{2}} \frac{\alpha hom \cdot Ehom \cdot \Delta T \cdot \alpha hom}{(1 - vhom)} \, dz$$

2.3. Validation

To validate the FSDT program, it must be compared with a small deflection program (Cheng, 2018). Below is Table 2.

Table 2. The validation of the results through comparison between X chang (Cheng, 2018) and the currently available program script (FSDT).

References	X. Cheng (SD)[16]	Present FSDT
b=a; a=30h	146.6	160.7
b=3a;a=30h	87.1	89.2
b=a;a=40h	88.1	90.4
b=3a;a=30h	48.9	50.2

3. Results and Discussion

The critical buckling temperature of polymer panels reinforced with glass particulates is shown for both square panels (Table 3) and rectangular panels with a length/width ratio of 2 (Table 4).

Table 3. The variation of the critical temperature for the square plate.

a/h; a=b	0%G-F	10%G-F	20%G-F
5	49.7	60.4	75.0
10	14.2	17.2	21.4
15	6.5	7.9	9.7
20	3.7	4.5	5.5
25	2.4	2.9	3.6
30	1.6	2.0	2.5
35	1.2	1.5	1.8
40	0.9	1.1	1.4
45	0.7	0.9	1.1
50	0.6	0.7	0.9

Table 4. The variation of the critical temperature for the rectangular plate.

a/h; a=b	0% G-F	10%G-F	20%G-F
5	29.8	36.2	44.9
10	8.0	9.8	12.1
15	3.6	4.4	5.5
20	2.1	2.5	3.1
25	1.3	1.6	2.0
30	0.9	1.1	1.4
35	0.7	0.8	1.0
40	0.5	0.6	0.8
45	0.4	0.5	0.6
50	0.3	0.4	0.5

The variation in critical buckling temperature for both square and rectangular plates follows similar trends. For square plates, the critical temperature decreases as the a/h ratio increases, indicating that thicker panels are more resistant to thermal buckling. The addition of glass particulates significantly improves the critical temperature, with the highest improvement observed at a 20% glass particulates content. For example, at a/h = 5, the critical temperature increases from 49.69°C for pure polymers to 74.97°C for 20% glass particulates reinforced polymers. However, the rate of improvement diminishes as the a/h ratio increases. For higher a/h values (e.g., 50), the increase in critical temperature is smaller, ranging from 0.59°C for pure polymers to 0.89°C for 20% glass particulates reinforced polymers. For rectangular plates, similar trends are observed, with the critical temperature decreasing as the a/h ratio increases. The overall effect of glass particulates reinforcement is also significant, especially at 10% and 20% particulates content. At a/h = 5, the critical temperature for pure polymers (0% s-f) is 29.79°C, while for 20% glass particulates, it increases to 44.91°C, indicating the positive influence of glass particulates on thermal stability. Again, as the a/h ratio increases, the improvement in critical temperature with the addition of glass particulates becomes less pronounced. At a/h = 50, the critical temperature rises from 0.33°C for pure polymers to 0.50°C for 20% glass particulates reinforced polymers.

4. Conclusion

The addition of glass particulates to polymers significantly enhances their thermal buckling resistance, particularly for thinner panels. This improvement is most noticeable at lower a/h ratios and diminishes as the panels become thicker. Glass particulates-reinforced polymers are thus especially suitable for applications where improved thermal stability is essential.

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