Sustainable Perlite-Based Insulation Materials from Agricultural Residues for Cold Chain Packaging: Thermal Performance Compared with EPS

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Abstract

Environmental concerns associated with expanded polystyrene (EPS), a widely used insulation material in cold chain packaging due to its excellent thermal insulation performance, low density, cost-effectiveness, and ease of large-scale manufacturing, have prompted the search for sustainable alternatives. This study evaluates the thermal performance of expanded perlite and perlite-based insulation materials incorporating agricultural residues, specifically sugarcane bagasse and coconut coir, for cold chain applications. The thermal properties of three formulations—expanded perlite, expanded perlite–bagasse, and expanded perlite–bagasse–coconut coir composites—were compared with EPS. Samples were fabricated into panel form using a free–form molding technique developed by the authors and adapted for this study (patent pending, Thai Patent Application No. 2303002175) and tested through temperature–time analysis under controlled conditions simulating cold chain environments. Key performance indicators included temperature retention relative to ambient conditions and thermal stability over time. The results show that expanded perlite sample exhibits thermal insulation performance slightly higher but comparable to EPS, with thermal conductivity values of 0.037 and 0.035 W/m·K, respectively. In addition, the incorporation of bagasse and coconut coir increased thermal conductivity to 0.045 and 0.047 W/m·K, resulting in reduced insulation efficiency. These findings are consistent with the temperature–time profiles, where pure expanded perlite shows behavior similar to EPS, while composite formulations exhibit faster temperature rise. Although the addition of agricultural residues may enhance structural integrity, pure expanded perlite demonstrates superior thermal insulation performance. In conclusion, expanded perlite presents strong potential as a sustainable alternative to EPS for cold chain packaging applications.

Keyword: agricultural residues, perlite-based bio-composites, thermal insulation, cold chain packaging, EPS alternative