31st Conference
Vibrations in Physical and Technical Systems – VIBSYS 2024
October 16–18, 2024, Poznań, Poland

ENHANCED DYNAMIC STRENGTH ANALYSIS OF CORRUGATED BOARD PACKAGING UNDER TRANSPORT LOADS

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ABSTRACT

The strength of cardboard packaging is crucial for ensuring the safety and integrity of goods during transportation, which frequently involves exposure to dynamic loads. Previous research by Mrówczyński et al. [1] presented a simplified method for analyzing the dynamic strength of corrugated board packaging. This method included static compressive strength analysis, frequency domain analysis of random vibrations to identify resonance frequencies, and subsequent dynamic analysis. The study validated the numerical models through laboratory tests on three-layer cardboard boxes, demonstrating the method's effectiveness in estimating the load capacity of various packages subjected to dynamic transport loads.

Building on this foundational work, the methodology was further enhanced in two significant areas: (1) material optimization and (2) advanced numerical modeling. Material optimization involved exploring hybrid corrugated board compositions with varying fluting and liner materials. By analyzing the impact of these materials on dynamic load resistance, more sustainable and cost-effective packaging solutions were developed without compromising strength. This approach aligns with the growing emphasis on sustainability in the packaging industry [2,3], addressing the need for reduced material use and lower costs while maintaining high performance [4,5].

Advanced numerical modeling was another critical area of development. Integrating machine learning algorithms into the modeling process enhanced the accuracy of failure point predictions and optimized box geometries in real-time. These algorithms were trained using extensive datasets obtained from both laboratory experiments and simulations, improving the predictive power of the models [6–10]. This integration allowed for the rapid adaptation of packaging designs to specific requirements, ensuring optimal performance under dynamic load conditions.

In addition to these technical enhancements, the vibration analysis was expanded to include multi-axis vibrations and real-world transport conditions. Traditional vibration analyses are often focused on unidirectional vibrations, which do not fully capture the complexity of real-world transport environments [11–14]. By simulating multi-directional and irregular vibrations, such as those experienced in long-haul trucking and maritime shipping, packaging performance in actual use scenarios was better predicted. This

comprehensive approach provided a more accurate assessment of packaging durability and reliability during transport.

Moreover, lifecycle assessment (LCA) was incorporated into the packaging design process. LCA evaluates the environmental impact of packaging materials and designs throughout their entire lifecycle, from production to disposal [15,16]. By integrating LCA with dynamic strength analysis, packaging solutions that are both robust and environmentally sustainable were developed. This ensures that packaging not only protects goods effectively but also minimizes environmental footprint, aligning with global sustainability goals.

The research directions significantly advanced the methodology for dynamic strength analysis of corrugated board packaging. By focusing on material optimization and advanced numerical modeling, the performance and sustainability of packaging solutions were enhanced. The integration of machine learning algorithms enabled real-time optimization and more accurate failure predictions, while expanded vibration analysis provided a more comprehensive understanding of packaging behavior under real-world conditions. On the other hand, the incorporation of LCA ensured that packaging solutions are environmentally responsible, addressing the growing demand for sustainable practices in the packaging industry. This outlines a comprehensive approach that improved the dynamic strength analysis of corrugated board packaging, with the ultimate goal of developing more effective, sustainable, and reliable packaging solutions for the transportation industry. Through material innovation, advanced modeling techniques, and a focus on sustainability, this research contributed to the advancement of packaging technology, ensuring the safe and efficient transport of goods while minimizing environmental impact.

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