Study on Improvement of Evaluation Methodology of Cushioning Packaging

Chen, Zhong

(Degree)
博士（工学）
(Date of Degree)
2013-09-25
(Date of Publication)
2014-09-01
(Resource Type)
doctoral thesis
(Report Number)
甲第5974号
(URL)
https://hdl.handle.net/20.500.14094/D1005974

(別紙様式３)

論 文 内 容 の 要 旨

氏　名　　仲 晨 (Chen ZHONG)

専　攻　　海事科学専攻

論文題目（外国語の場合は，その和訳を併記すること。）

Study on Improvement of Evaluation Methodology of Cushioning Packaging

（緩衝包装機能評価手法の高度化に関する研究）

指導教員　　斎藤 勝彦

Economic globalization is increasing the economic interdependence of national economies across the world through a rapid increase in cross-border movement of goods in recent years. Distribution of goods trends to globalization. This trend causes that package of goods is more important than ever.

For safe delivery of a product from manufacturer to consumers, adequate cushioning is indispensable. Using numerous cushioning materials and packaging methods, many package versions can be designed. Considering the relationship of product and package design, if the package cannot make up the difference between the product ruggedness and the environment inputs, 'under package' occurs and product damage will most likely result. Conversely, if the package is provided too much protection, the situation called 'over package' is economically wasteful because money is being wasted on protection which is not required. Therefore, packaging engineers seek 'optimal package' that provides sufficient protection to the products at an economical cost. To accomplish this, the performance of the cushioning materials that are used in transport packaging must be tested before the materials are applied in the packaging design. In addition, the whole cushioning package must be tested to confirm whether it provides sufficient protection to the products.

Cushioning package materials are usually evaluated by traditional drop testing methods, such as free fall and controlled shock tests. Both tests are considered to yield the same results when the test dummy is dropped from a given height. The basis for this assumption is the equivalent drop theory. Physical test methods can be supplemented by a number of widely used simulation methods.

In addition, a typical design procedure for the cushioning package comprises of the following four steps. Step 1—Define the distribution environment (i.e. the shock and vibration). The environment must be defined first to design package. Step 2—Define product fragility. The product fragility represents the product's sensitivity to shock and vibration. Step 3—Design the cushioning package. First, the cushioning material may need to be tested, and then the shock cushioning and vibration transmissibility curves are plotted. Second, from the test results, we can determine the type, size and thickness of the cushioning material. Finally, the entire cushioning package should be configured. Step 4—Perform verification tests for entire package. This step confirms whether the package design is optimized. If all testing requirements are met, optimal package design is accomplished. Otherwise, the designers must return to Step 3 and repeat this procedure.

However, traditional drop test methods are limited by the following three shortcomings. First, in the traditional equivalent drop theory, the package is assumed to behave as a linear mass–spring model. Since no packaging materials satisfy this assumption, the applicability of the traditional equivalent drop theory is limited by experimental errors. Second, the safety of a test product is not guaranteed under traditional drop testing, while traditional simulation methods are not sufficiently accurate for the stringent requirements of packaging materials.

Third, for traditional testing methods, design requirements are not usually met in a single verification testing in practice. Repetition of Steps 3 and 4 two or three times is normal. A worst-case scenario occurs when an inappropriate cushioning material was applied. In this case, large quantities of labor and material resources are undoubtedly required.

The objective of this study is to issue aforementioned questions. We resolve the first shortcoming by a new theory called the 'friction equivalent drop theory'. On the basis of this theory, we propose a new test method called 'the hybrid drop test' that integrates the traditional drop test and simulation methods. The hybrid drop test ensures the safety of the test product and improves test efficiency.

This dissertation comprises six chapters and an appendix.

Chapter 1 presents the research background, methods and purposes, focusing on two traditional evaluation testing methods for cushioning material and packaged product. Traditional and damping equivalent drop theories and digital simulation methods are also described.

Chapter 2 begins with the need for a new equivalent drop theory, and then introduces a new physical model called the 'friction viscous-damping model'. On the basis of this model, we theoretically deduced shock response equations of the free fall and controlled shock tests. Finally, a friction equivalent drop theory was theoretically elaborated. Due to a nonlinear characteristic of the friction viscous-damping model, some approximate solutions for nonlinear system such as average method and equivalent linearization method were applied during the deduction of the two shock response equations. Meanwhile, simulation software called MapleSim was used to carry out a digital simulation.

Chapter 3 describes a series of verification tests for proofing the feasibility of the friction equivalent drop theory. A preliminary verification test based on a simple corrugated sleeve was first performed. The equivalent free-fall height was decided as 60 cm. The results showed that the equivalent accuracy is improved after an application of the friction equivalent drop theory. To obtain robust proof, the further verification test was performed for a range of materials and stresses. A corrugated sleeve and pulp mould cushions were used as the test materials. Verification tests proofed the applicability of the friction equivalent drop theory to both structural corrugated sleeve and pulp mould cushions. The corrective effects vary with stress but become more prominent toward the lowest point of the cushion curve. The predictive accuracy of the hybrid drop test is sufficiently high for practical application in cushion package design.

Chapter 4 introduces the hybrid drop test, a novel evaluation testing method based on the friction equivalent drop theory developed in Chapter 2. The chapter begins with a conceptual overview of the new testing method, followed by a flowchart. Finally, calculation of the parameters of the FVD model is explained in detail.

Chapter 5 describes the verification test which proofs the feasibility of the hybrid drop

test, similar to the friction equivalent drop theory in Chapter 3. A mockup was constructed to represent a real product—printer. Edge-coupling pulp mould was used as the cushioning material. The controlled shock tests were performed and the experimental data such as acceleration, velocity change were recorded. Data statistics was made on the basis of numerous experimental data. The results showed that hybrid drop test is sufficiently accurate for practical applications.

Chapter 6 presents the summary of this dissertation.

Appendix lists symbols and acronyms used in this dissertation.

Summarily, through developing a new equivalent drop theory and proposing a new evaluation testing method, we improved evaluation methodology of cushioning packaging. Using the hybrid drop testing method, we can predict the PRA for a specified package design at higher drop heights by performing a single, low-height drop test.The hybrid drop testing method provides packaging researchers with an alternative testing choice. It also ensures the safety of the test product and improves test efficiency. We expect that this new testing method will become of valuable assistance in futer packaging design.

(別紙１)　　論文審査の結果の要旨

氏名	仲 晨 (Chen ZHONG)		
論文題目	Study on Improvement of Evaluation Methodology of Cushioning Packaging (緩衝包装機能評価手法の高度化に関する研究)		
審査委員	区　分	職　名	氏　　名
	主　査	教授	齋藤勝彦
	副　査	教授	阿部晃久
	副　査	教授	河口信義
	副　査		
	副　査		印

要　　旨

落下衝撃から包装内容品を保護するための緩衝材の性能は、動圧縮試験によって評価されるが、複雑な形状の構造体緩衝材では、動圧縮試験ができないため、衝撃試験装置を用いた等価落下試験で評価される。等価落下試験では、発生させる衝撃台の正弦半波パルスの速度変化と等しい衝突速度となる落下高さが等価自由落下高さであると規定されており、緩衝系が線形バネ-質量１自由度系とみなせる場合には実用上問題ないが、実際の緩衝系は減衰や摩擦の影響が無視できない。

そこで本論文では、緩衝材性能評価として、従来の方法による等価落下試験の結果が、必ずしも自由落下と等価とみなせるほどではないことを実験的に明らかにするとともに、減衰や摩擦の影響を考慮した等価落下理論に基づいた等価落下試験の方法を提案している。さらに、減衰・摩擦等価落下モデルによる等価落下試験を行い、自由落下との等価度を実験的に確認している。

一方、緩衝包装設計された包装品の性能を確認するためには、最終的に落下試験が行われるが、包装内容品（実製品）が非常に高価なプロトタイプモデルやサンプル品の場合、試験によって破損した場合の代替品がなく、試験の実施が困難な場合がある。

そこで本論文では、緩衝包装品をバネ・減衰・摩擦並列モデル化した数値計算を併用する新しい「ハイブリッド落下試験」の概念を提案し、これによって包装内容品を破損させることなく、緩衝包装の性能を確認できることを明らかにしている。

本論文は以下の６章から構成されている。

第１章では、研究の背景と目的を述べるとともに、等価落下試験の方法について説明している。

第２章では、減衰と摩擦の影響が混在する衝撃応答・等価落下モデルについて提案している。

第３章では、段ボールスリーブ形状およびパルプモウルド成形緩衝材について、減衰・摩擦等価落下モデルによる等価落下試験を行い、自由落下との等価度を実験的に確認している。

第４章では、緩衝包装品をバネ・減衰・摩擦並列モデル化した数値計算を併用する新しい「ハイブリッド落下試験」の概念を提案している。

第５章では、「ハイブリッド落下試験」によって包装内容品を破損させることなく、緩衝包装の性能を確認できることを明らかにしている。

第６章では、結語として研究をまとめている。

以上のように本研究で得られた成果は、合理的な緩衝包装設計の確立に資することが期待でき、貨物の安全輸送を支える包装技術の向上に貢献できる。よって、学位申請者の仲 晨 (Chen ZHONG)は、博士（工学）の学位を得る資格があると認める。