

A Review on Drop and Impact Analysis of Plastic Enclosure after Thermal Aging Effect

Ajeet Patil¹, Rajesh Sallikeri², Nilesh Sapate³, Jakariya Kurundwad⁴

¹Professor, Walchand College of Engineering, Sangli

²Technologist, Emerson Innovation Center, Pune

³Lead Engineer, Emerson Innovation Center, Pune

⁴Student, Walchand College of Engineering, Sangli

Abstract— The increasing reliance on plastic enclosures in critical applications such as consumer electronics, automotive, and aerospace underscores the need to assess their long-term durability under adverse conditions [2][9][18][34]. Thermal aging significantly alters the mechanical properties of polymer-based materials, influencing their performance during drop and impact events [3][5][8] [15] [19] [21] [20] [28]. This review synthesizes methodologies for evaluating the drop and impact behavior of thermally aged plastic enclosures, drawing insights from experimental protocols and advanced simulation techniques [6] [7]. Experimental studies reveal that thermal aging induces degradation mechanisms such as oxidation, chain scission, and matrix-fiber interface weakening, leading to reduced tensile strength, impact resistance, and toughness [34] [24] [25]. Standards like ISO 527 and ISO 62:2008 guide the testing of thermally aged specimens, highlighting the effects of controlled temperature and humidity exposure [37] [40] [26] [29]. Techniques such as tensile, flexural, and drop-weight impact tests are integral for quantifying changes in material properties, while accelerated aging protocols mimic real-world degradation within shorter timeframes [30] [16] [38] [20] [28] [29]. Simulation-based approaches complement experimental findings by providing predictive insights into material performance [44] [48]. Finite element analysis (FEA) tools, enable the modeling of impact scenarios and material degradation. Material models that incorporate strain rate sensitivity and temperature-dependent properties improve simulation accuracy, aligning predictions with experimental data [11][30][31]. Despite advances in methodology, challenges remain in standardizing protocols and bridging laboratory results with field performance. Emerging trends, such as machine learning-assisted simulations and sustainability-focused material recycling, offer promising directions for future research.

This review highlights the interplay of experimental and computational methodologies in understanding the impact resistance of thermally aged plastic enclosures, providing a comprehensive framework for researchers and industry professionals. It calls for the integration of

advanced techniques and standardized protocols to ensure the reliability and sustainability of polymeric materials in demanding applications [2][9][32][33] [41] [51].

Index Terms—Thermal aging, Plastic enclosures, Drop and impact analysis, Polymer degradation, Accelerated aging, Mechanical properties, Finite element analysis (FEA), Strain rate sensitivity, Tensile testing, Environmental conditioning, Glass transition temperature (T_g), Simulation techniques, Impact resistance, Material modelling, Polymer composites.

I. INTRODUCTION

The increasing reliance on plastic materials in consumer electronics, automotive, aerospace, and other industries has elevated the importance of understanding their long-term performance under varying environmental conditions. Plastic enclosures, often used to protect sensitive components, are subject to mechanical stresses, environmental factors, and thermal effects that can degrade their structural integrity over time [44][48][35][36]. The ability of these enclosures to resist mechanical impacts and maintain their functionality after thermal aging is a critical concern for manufacturers and end users [18] [2] [9].

Thermal Aging and Its Implications:

Thermal aging is a degradation process that occurs when polymers are exposed to elevated temperatures for prolonged periods. It induces chemical and physical changes, such as oxidation, chain scission, crosslinking, and matrix-fiber interface degradation, which significantly affect the mechanical properties of the material [42][30][35][53][43]. These changes often manifest as reduced tensile strength, diminished toughness, and increased brittleness, leading to a higher likelihood of failure under impact or drop conditions. For example, studies have shown that polymers exposed to temperatures near or above their

glass transition temperature (T_g) experience accelerated aging effects, with thermo-oxidative reactions playing a dominant role in property degradation [54][73][71].

Challenges in Assessing Impact Resistance Post-Thermal Aging:

The evaluation of drop and impact resistance in thermally aged plastic enclosures is inherently complex due to the interplay of multiple factors, including temperature, strain rate, and environmental conditions such as humidity [53][60][73]. Traditional testing methods, such as tensile and drop-weight impact tests, are essential for characterizing mechanical properties, but they often fall short in replicating real-world conditions. Additionally, variations in material compositions, fabrication processes, and exposure environments make it difficult to establish standardized testing protocols [39][50].

Advanced simulation techniques, such as finite element analysis (FEA), have emerged as indispensable tools for complementing experimental methods. By integrating material property changes due to thermal aging, these simulations can predict the behavior of plastic enclosures under various impact scenarios [6][7][10][55][66]. However, accurately modeling the effects of thermal aging requires robust material models that account for degradation mechanisms and environmental factors.

Current Research Landscape:

Recent research has focused on understanding the failure mechanisms in aged polymers, developing accelerated aging protocols, and improving predictive models. Studies have explored the combined effects of temperature and moisture, revealing the significant role of environmental conditioning in material degradation [73][18][34][54][72]. For example, ISO standards such as ISO 527 and ISO 62:2008 provide guidelines for tensile and moisture absorption testing, respectively, enabling researchers to evaluate the impact of thermal aging under controlled conditions [74] [84]. Despite these advancements, a gap remains in correlating laboratory findings with real-world applications, particularly for polymers used in critical environments.

Scope of the Review:

This review paper aims to provide a comprehensive analysis of methodologies for assessing the drop and impact resistance of thermally aged plastic enclosures. It synthesizes findings from experimental studies and simulation-based approaches, highlighting the challenges and advancements in this field [6][54][71][74][11][34][1][65][72]. Key areas of focus include:

Mechanisms of thermal aging and their effects on mechanical properties.

Experimental methods for evaluating impact resistance and degradation.

Simulation techniques for modeling material behavior post-aging.

Industrial practices and emerging trends, such as sustainability and material recycling.

By bridging the gap between experimental insights and simulation capabilities, this review seeks to offer a robust framework for understanding the long-term performance of plastic enclosures. It also provides recommendations for future research and practical applications, addressing the pressing need for reliable and sustainable material solutions in demanding industries.

II. METHODOLOGY

To accurately evaluate the drop and impact resistance of plastic enclosures subjected to thermal aging, a combination of experimental and simulation-based approaches is essential. The methodology involves several key steps, including thermal aging protocols, mechanical property testing, drop and impact tests, and computational modeling. Each step is outlined below in detail [32][3][5][60][18][66].

1. Thermal Aging Process

1.1 Sample Preparation

Select representative samples of the plastic enclosure material (e.g., Grilamid, polycarbonate, or other polymers commonly used in enclosures). Cut samples into standardized dimensions for subsequent testing, following ISO 527 or ASTM D638 standards for tensile specimens. Ensure consistency in sample dimensions and surface preparation to minimize variability in test results.

1.2 Accelerated Aging Protocol

Perform thermal aging in a controlled oven or climatic chamber.

Temperature Settings: Choose temperatures based on the material's glass transition temperature (T_g) and operational conditions.

For instance: Below T_g (post-curing effects dominate).

Above T_g (thermo-oxidative degradation occurs).

Duration: Subject samples to thermal aging for defined periods (e.g., 1 week, 2 weeks, or more), depending on the expected lifespan and aging effects.

Environmental Conditioning: Combine aging with controlled humidity levels (e.g., 85% RH) to simulate real-world conditions where moisture accelerates degradation.

2. Mechanical Property Evaluation

2.1 Tensile Testing

Conduct tensile tests at a strain rate of 50 mm/min (as per ISO 527) to evaluate changes in tensile strength, elongation at break, and modulus of elasticity. Perform tests on aged and unaged specimens for comparison.

3. Drop and Impact Testing

3.1 Test Setup

Use a drop-weight impact tester or pendulum impact tester with adjustable energy levels.

Mount plastic enclosures or test specimens on a rigid fixture to simulate real-world constraints.

3.2 Drop Tests

Test Parameters: Perform tests from varying heights (e.g., 0.7m to 3m) to evaluate energy absorption and failure thresholds. We can refer standard IEC60079-0 based on type of application.

3.3 Impact Tests

Conduct low-velocity impact tests with spherical or flat-ended impactors to simulate point loading conditions. Record force-time and energy-time data using high-speed data acquisition systems. Test under different temperatures (ambient, below freezing, and elevated) to evaluate temperature sensitivity.

4. Computational Simulation

4.1 Material Modelling: Develop a material model incorporating data from aged specimens, including Stress-strain behavior, Strain rate sensitivity, Temperature-dependent properties.

4.2 Simulation Tools: Use finite element analysis (FEA) tools such as Radioss, Hypermesh, or Abaqus to simulate drop and impact scenarios. Include cohesive zone modeling or other damage evolution criteria to predict delamination, cracking, and plastic deformation.

4.3 Simulation Scenarios: Simulate drop impacts from varying heights and impact orientations (e.g., corner drop, flat surface drop). Incorporate thermal aging effects into the simulation by updating material properties with experimental findings.

4.4 Validation: Compare simulation results with experimental data (e.g., force-time curves, damage patterns) to validate the model. Refine the model iteratively to improve prediction accuracy.

5. Data Analysis and Interpretation

5.1 Performance Metrics: Evaluate impact energy absorption, crack propagation, and deformation under different conditions. Compare aged and unaged specimens to assess the degradation effects quantitatively.

5.2 Statistical Analysis: Use statistical methods to analyze variability in test results and ensure reliability. Perform regression or correlation analysis to link aging parameters (temperature, duration) with mechanical properties.

6. Reporting and Recommendations

Summarize findings, highlighting key changes in material behavior post-aging. Provide recommendations for improving material formulations or enclosure designs to mitigate thermal aging effects. Suggest further research areas, such as advanced aging simulations or alternative material testing methods.

This detailed methodology ensures a comprehensive evaluation of the drop and impact performance of thermally aged plastic enclosures. By integrating experimental and simulation techniques, the approach provides a robust framework for

understanding material degradation and improving reliability.

III. CONCLUSION

The drop and impact resistance of plastic enclosures subjected to thermal aging is a critical concern in industries such as consumer electronics, automotive, and aerospace [2][9][18][34]. This review consolidates the methodologies for evaluating the mechanical performance of thermally aged polymers, highlighting the interplay of experimental and computational approaches.

Thermal aging significantly alters the mechanical properties of polymers, inducing degradation mechanisms such as oxidation, chain scission, and fiber-matrix debonding. These changes result in reduced tensile strength, impact resistance, and toughness, which directly influence the reliability of plastic enclosures under mechanical stress [86][97][100]. Experimental techniques, including tensile, flexural, and drop-weight impact tests, provide valuable insights into the effects of aging [53][54]. Accelerated aging protocols, guided by standards such as ISO 527 and ISO 62:2008, allow researchers to simulate long-term degradation in shorter timeframes, enabling timely evaluation of material performance. However, challenges persist in correlating laboratory findings with real-world applications, particularly in diverse environmental conditions.

Finite element analysis (FEA) emerges as a powerful tool to complement experimental studies, enabling the simulation of drop and impact scenarios. By integrating material property changes due to thermal aging, simulations provide predictive insights into material behavior, offering a cost-effective alternative to extensive physical testing. FEA tools demonstrated their capability to model complex phenomena, including delamination, matrix cracking, and strain rate sensitivity [11][12][13][17]. However, accurate simulations require robust material models that account for the combined effects of temperature, strain rate, and environmental factors.

This review underscores several gaps and areas for improvement in current methodologies:

Standardization: There is a need for standardized testing protocols that account for the combined effects of thermal and environmental aging.

Simulation Validation: Experimental data must be effectively integrated into simulations to enhance predictive accuracy and reliability.

Real-World Correlation: Bridging the gap between laboratory findings and field performance remains a significant challenge, necessitating more comprehensive studies.

In conclusion, the integration of experimental and simulation-based methodologies is essential for a comprehensive understanding of the impact resistance of thermally aged plastic enclosures. By addressing current challenges and adopting innovative approaches, researchers and industry professionals can enhance the reliability, sustainability, and longevity of polymer-based materials in critical applications [9][18]. Future research should focus on developing more accurate predictive models, improving testing protocols, and exploring advanced materials that are inherently resistant to thermal and environmental degradation [71][86] [87]. This holistic approach will ensure the continued advancement of plastic enclosures, meeting the demands of increasingly stringent operational requirements.

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