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THE CO-RELATION BETWEEN LOI AND FIRE RATING FOR POLYMERIC MATERIALS

Himanshu Kumar, Vivek Thakre, Aditya Sharma, Tisha Meena, and Sharib Imam
B-tech (Fire Engineering) Student at NFSC, Nagpur, MINISTRY OF HOME AFFAIRS GOVT.OF INDIA.

Suresh Lade
Asst. Professor/Consultant, National Fire Service College, Nagpur

***Abstract*: This research paper investigates the correlation between Limiting Oxygen Index (LOI) and UL 94 fire ratings for polymeric materials. A novel mathematical approach using the floor function is proposed to discretize continuous LOI measurements into categorical UL 94 classifications. The study examines the theoretical foundations of LOI testing (ASTM D2863, ISO 4589-2) and UL 94 vertical burn tests, highlighting their methodologies and significance in fire safety engineering. A comprehensive analysis of various polymers demonstrates the application and limitations of the proposed correlation. While confirming a general trend between higher LOI values and better UL 94 ratings, the research also underscores the complexity of flame-retardant behaviour and the influence of factors beyond oxygen index, such as char formation and melt behaviour. The paper concludes that while the LOI-based formula provides a useful approximation, it should be used in conjunction with standardized tests for accurate fire safety assessments. This study contributes to the field by offering a quantitative framework for relating LOI to UL 94 ratings, potentially streamlining material selection processes and guiding the development of flame-retardant polymers.**

***Keywords:* Mathematical correlation, floor function, ASTM D2863, ISO 4589-2, vertical burn test, flame resistance, flame-retardant polymers, Fire Ratings…..**

1. Introduction-Comprehensive Flammability Correlation

This research paper investigates the relationship between Limiting Oxygen Index (LOI) and UL 94 fire ratings, two key metrics for evaluating the flammability of polymeric materials. A novel mathematical approach is introduced to correlate LOI values with UL 94 classifications, employing the floor function to convert continuous LOI measurements into categorical fire ratings. The proposed formula,

provides a systematic method for estimating UL 94 ratings based on LOI data[4] The study examines the theoretical underpinnings of LOI testing (ASTM D2863, ISO 4589-2) and UL 94 vertical burn tests, emphasizing their methodologies and relevance to fire safety engineering

The research explores advanced discretization techniques, including supervised and unsupervised methods, to enhance the categorization of LOI values into UL 94 ratings[7]. A detailed comparison between calculated fire ratings and actual UL 94 classifications for various polymers highlights the model's predictive strengths and limitations[4] While confirming a general trend of higher LOI values correlating with superior UL 94 ratings, the study underscores the complexity of flame-retardant behaviour influenced by factors like char formation and melt behaviour [9,10]. These findings position the LOI-UL 94 correlation as a valuable tool for preliminary fire performance evaluation and material development [11,12]

2. Testing Methodology and Rationale

The Limiting Oxygen Index (LOI) test and UL 94 flammability ratings are two critical methodologies in assessing the fire resistance of materials, particularly polymers. Understanding their relationship is crucial for material scientists, fire safety engineers, and product designers seeking to optimize fire performance while meeting regulatory requirements.

The LOI test, standardized under ASTM D2863 and ISO 4589-2, determines the minimum oxygen concentration required to support combustion of a material [1]. In this test, a small specimen is placed vertically in a glass chimney, and a mixture of oxygen and nitrogen is passed through it. The oxygen concentration is gradually reduced until the specimen no longer supports combustion for a specified time or burning length. The LOI value is expressed as a percentage, with higher values indicating greater flame resistance [2].

UL 94, on the other hand, is a set of flammability tests developed by Underwriters Laboratories that evaluate how plastic materials used in devices and appliances respond to small flame ignition sources [16]. The UL 94 standard includes several test methods, with the vertical burn test being the most common for assessing flame spread. Materials are classified into categories such as HB, V-2, V-1, V-0, 5VB, and 5VA, with V-0 being one of the highest flame-resistant ratings [5].

Establishing a correlation between LOI values and UL 94 ratings is valuable for several reasons:

1. Predictive capability: It allows for preliminary assessment of a material's likely UL 94 performance based on its LOI, potentially reducing the need for extensive initial testing.

2. Material development: Polymer scientists can use this relationship to guide the development of new flame-retardant materials, targeting specific LOI ranges to achieve desired UL 94 ratings.

3. Quality control: Manufacturers can use LOI testing as a rapid quality control measure to ensure consistent flame-retardant performance before conducting more time-consuming UL 94 tests.

4. Comparative analysis: The correlation provides a quantitative basis for comparing the flame resistance of different materials across a continuous spectrum (LOI) and discrete categories (UL 94).

5. Regulatory compliance: Understanding this relationship helps in selecting materials that are likely to meet specific fire safety regulations in various industries.

6. Cost-efficiency: By predicting UL 94 performance through LOI testing, companies can potentially reduce the number of formal UL 94 tests required, saving time and resources.

The testing process for both LOI and UL 94 involves careful specimen preparation, controlled environmental conditions, and precise measurement techniques. For LOI, the test apparatus typically includes a glass chimney, gas flow controls, and ignition sources. UL 94 testing requires specific specimen sizes, conditioning procedures, and flame application methods depending on the desired classification [9].

While the correlation between LOI and UL 94 ratings is not perfect due to the complex nature of material combustion, establishing a mathematical relationship provides valuable insights into material behaviour under fire conditions. This relationship serves as a powerful tool in the broader context of fire safety engineering and materials science, enabling more informed decisions in material selection and development for applications where fire resistance is critical.

3. ASSESSMENT FRAMEWORK

The correlation between Limiting Oxygen Index (LOI) and fire ratings, particularly UL 94 classifications, is a fundamental aspect of fire safety engineering and materials science. This relationship provides crucial insights into the flammability characteristics of polymers and other materials, enabling more informed decisions in product design, material selection, and regulatory compliance.

LOI, defined as the minimum concentration of oxygen required to support combustion, offers a quantitative measure of a material's inherent flame resistance [7]. The test, conducted according to ASTM D2863 or ISO 4589-2 standards, involves placing a specimen in a controlled atmosphere of oxygen and nitrogen, gradually reducing the oxygen concentration until the material no longer supports combustion [2]. The resulting LOI value, expressed as a percentage, provides a continuous scale for assessing flame resistance.

In contrast, UL 94 flammability ratings, developed by Underwriters Laboratories, offer a discrete classification system based on a material's response to small flame ignition sources [3,5]. The UL 94 vertical burn test evaluates flame spread, burning time, and dripping behaviour, categorizing materials into ratings such as HB, V-2, V-1, and V-0, with V-0 representing the highest level of flame resistance [7].

The relationship between LOI and UL 94 ratings is complex and not always linear. Generally, materials with higher LOI values tend to achieve better UL 94 classifications [4,1]. For instance, polymers with LOI values below 21\% typically exhibit poor flame resistance and often receive HB ratings, while those with LOI values above 30\% are more likely to achieve V-0 ratings [14,11]. However, this correlation is not absolute. Factors such as material thickness, additives, and specific burning characteristics can influence UL 94 performance independently of LOI [6,9].

4. RESULT

1. Material-Specific Variations: The research revealed that while higher LOI values generally correlate with better UL 94 ratings, this relationship is not universally consistent across all polymer types. Factors such as char formation, melt behaviour, and material-specific burning characteristics can significantly influence UL 94 performance independently of LOI.

2. Limitations of the Model:} The study highlighted discrepancies between predicted and actual UL 94 ratings, particularly for materials like rigid PVC, which achieve better UL 94 ratings than predicted by LOI alone. This underscores the importance of considering multiple factors in fire performance assessment.

3.Applicability in Material Development: Despite its limitations, the LOI-UL 94 correlation provides a valuable screening tool for polymer scientists and manufacturers. It offers a rapid, cost-effective method for preliminary assessment of flame-retardant properties, potentially streamlining the material development process.

4. Regulatory Implications: The research emphasizes the need for a comprehensive approach to fire safety assessment in regulatory compliance. While LOI testing offers valuable insights, it should not be used as a sole predictor of UL 94 ratings in regulatory contexts.

5. Future Research Directions: The study points towards the need for more sophisticated models that incorporate additional factors influencing fire performance. Machine learning techniques and larger datasets could potentially refine the LOI-UL 94 correlation, offering more accurate predictive capabilities.

6. Environmental Considerations: The research touches upon the importance of considering environmental conditions and

material aging in the relationship between LOI and UL 94 ratings, suggesting an area for further investigation.

5. CONCLUSION:

This research contributes significantly to the field of fire safety engineering by providing a quantitative framework for relating LOI to UL 94 ratings. While the proposed model offers a useful approximation, it also highlights the complexity of flame-retardant behavior and the need for comprehensive testing.

The findings of this study have practical implications for material scientists, fire safety engineers, and product designers. By understanding the strengths and limitations of the LOI-UL 94 correlation, stakeholders can make more informed decisions in material selection, development of flame-retardant polymers, and regulatory compliance strategies.

Moving forward, the integration of this knowledge into predictive modeling tools, coupled with ongoing research into advanced flame-retardant technologies, promises to enhance fire safety across various industries. However, it is crucial to remember that while such models and correlations provide valuable insights, they should always be used in conjunction with standardized testing methods to ensure the highest levels of fire safety.

This research underscores the dynamic nature of fire safety engineering and the ongoing need for innovative approaches to material flammability assessment. As new materials and technologies emerge, continued research in this field will be essential to maintain and improve safety standards in an ever-evolving landscape of materials and applications.

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