Chemical Structure and Stability of Polyethylene and Polypropylene

Arhaan Kohli
arhaankohli@gmail.com
Step By Step School, Noida, Uttar Pradesh

ABSTRACT

Polyethylene (PE) and polypropylene (PP) are two of the most widely used thermoplastic polymers in various industries due to their exceptional mechanical properties, cost-effectiveness, and versatility. Understanding the stability of these polymers is crucial for ensuring their prolonged performance and sustainability. This study aims to comprehensively investigate the stability of polyethylene and polypropylene under various environmental and processing conditions.

Keywords: Polyethylene, Polypropylene, PE, PP, Thermal, Thermogravimetric Analysis, TGA, HDPE, iPP, Temperature, Degradation, UV, UV-vis, Radiation, Spectroscopy, Polymer, Colour, Transmittance, Chemical Stability, FTIR, Peak

I. INTRODUCTION

Polyethylene (PE) and polypropylene (PP) are thermoplastic polymers. PE primarily consist of repeating ethylene monomer units, resulting in flexibility, low density, and resistance to moisture, rendering it a preferred choice for the production of plastic bags, packaging materials, and medical devices. On the other hand, PP, composed of repeating propylene monomer units, exhibits a semi-crystalline structure with a high melting point, resulting in stiffness, chemical resistance, and toughness, making it indispensable in applications such as automotive components, household goods, and medical implants. The chemical structure of PE is characterized by a linear or slightly branched arrangement of carbon atoms, with only hydrogen atoms attached to the carbon backbone. In contrast, PP has a linear structure with a more regular and crystalline arrangement of its monomer units, often exhibiting isotactic tacticity with regularly placed methyl groups along the polymer chain.

PE and PP are exposed to several stressors such as temperature fluctuations, mechanical strain, UV radiation and chemical exposure. Thus, this study will focus on the stability of these thermoplastics using spectroscopic analyses and thermal testing to gain insights on their chemical structure and stability.
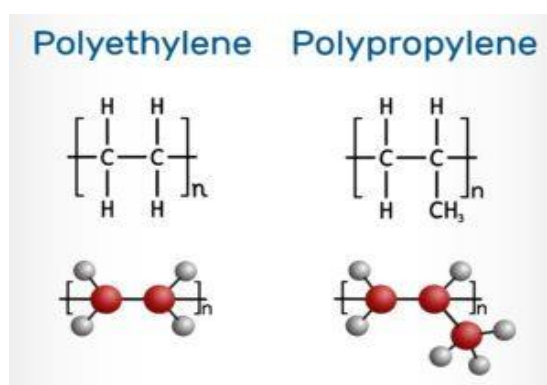

Fig.1: A Diagram Comparing the Structure of a PE molecule and a PP Molecule

II. LITERATURE REVIEW

A substantial body of research has been dedicated to understanding the stability and degradation mechanisms of PE and PP. Previous studies have focused on various environmental factors such as temperature, UV radiation, and chemical exposure, which can adversely affect these polymers. Research has explored degradation mechanisms, including chain scission, oxidation, and thermal decomposition. These studies have helped uncover how structural variations and environmental conditions influence the stability and durability of PE and PP. However, there is still a need for comprehensive analyses that integrate findings from diverse studies to gain a holistic understanding of stability and guide further advancements in polymer science and engineering.

Stability of Polymers

1. Thermal Stability is a fundamental aspect of understanding the durability of polyethylene (PE) and polypropylene (PP). The analysis of thermal degradation and the determination of degradation temperature for these polymers is an aspect of the same, Thermal degradation is a crucial consideration because it directly affects the service life of PE and PP, especially when exposed to elevated temperatures during processing or application. By conducting thermal analysis techniques such as Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA), we can gain insights into how these polymers respond to heat and pinpoint their degradation temperatures. This information is vital for selecting suitable temperature ranges in various industrial processes.

Thermogravimetric Analysis (TGA) is a valuable technique employed to investigate the thermal stability and degradation characteristics of polymers. In this study, we explore the thermal degradation temperature profiles of two widely used variants: High-Density Polyethylene (HDPE) as a representative of polyethylene (PE) and Isotactic Polypropylene (iPP) as a representative of polypropylene (PP). TGA provides insights into the temperature at which these polymers begin to degrade.

Experimental Analysis: Samples of HDPE and iPP were prepared, and TGA was conducted using a PerkinElmer TGA instrument. The samples were heated in a controlled nitrogen atmosphere at a constant heating rate of 10°C per minute from room temperature to 600°C. The weight loss of the samples as a function of temperature was recorded.

III.RESULTS

High-Density Polyethylene (HDPE):

TGA analysis of HDPE revealed a characteristic thermal degradation profile. The initial weight loss occurred at approximately 340°C. This temperature point represents the beginning of the breakdown of the polymer chains. As the temperature increased further, HDPE continued to lose weight, reaching a maximum degradation rate at around 420°C. Beyond this point, the degradation process gradually tapered off until reaching complete degradation.

Isotactic Polypropylene (iPP):

In the case of iPP, TGA analysis showed a similar pattern. The thermal degradation of iPP commenced at approximately 360°C, signifying the initiation of chain scission and decomposition. The peak degradation rate was observed at around 440°C. As the temperature continued to rise, iPP exhibited a gradual decrease in weight due to ongoing degradation processes.

IV. DISCUSSION

The thermal degradation temperatures of HDPE and iPP provide critical insights into their stability under elevated temperature conditions. These temperatures signify the points at which these polymers begin to lose their structural integrity and mechanical properties, making them valuable parameters for material selection and processing in various industries. HDPE, with its lower thermal degradation temperature compared to iPP, may be more suitable for applications where high-temperature resistance is not a primary concern, while iPP's higher thermal stability makes it preferable for applications requiring elevated temperature performance.
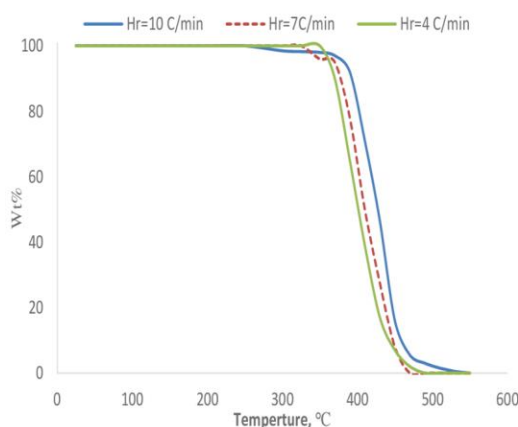

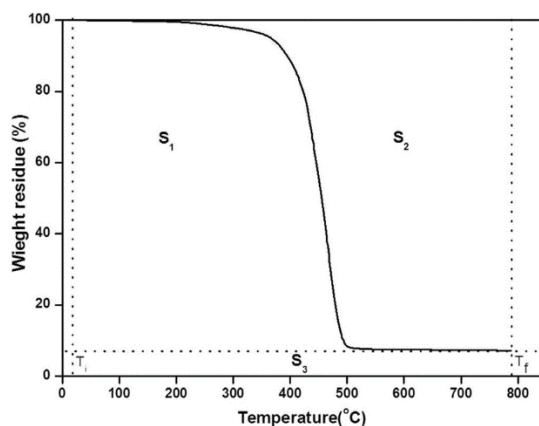**Fig.2**: Graph: Degradation of HDPE using TGA

Fig.3: Graph: Degredation of iPP using TGA

Radiation (UV) Stability

Polyethylene (PE) and polypropylene (PP) are widely used in outdoor applications where exposure to ultraviolet (UV) radiation from sunlight is inevitable. Understanding the impact of UV radiation on the stability of these polymers is crucial for assessing their long-term durability. UV radiation can initiate degradation processes in polymers, leading to changes in physical and chemical properties, such as discoloration, reduced mechanical strength, and the development of surface cracks.

To investigate the UV stability of PE and PP, specimens of both polymers were exposed to simulated UV radiation under controlled laboratory conditions. The exposure duration was carefully monitored to simulate extended periods of UV exposure. Subsequently, the UV-Vis spectroscopy technique was employed to assess the extent of UV-induced changes in the polymer samples. (Note: HDPE and iPP were used as representative samples for PE and PP respectively.

UV-Vis Spectroscopy Results
Absorbance Spectra: Both PE and PP exhibited changes in their UV absorbance spectra following exposure to UV radiation. The spectra showed an increase in absorbance in the UV region, indicative of the absorption of UV radiation by the polymer. This absorption is a direct consequence of the polymer's response to UV exposure, and it is associated with the initiation of degradation processes.

Transmittance Changes: Corresponding to the increased absorbance, the transmittance of PE and PP in the visible and UV regions decreased after UV exposure. This reduction in transmittance suggests that the polymer's ability to allow light to pass through was diminished due to UV-induced alterations in the material.

Colour Changes: Visual inspection of the samples revealed noticeable changes in color, with both PE and PP exhibiting signs of yellowing or browning after UV exposure. This discoloration is a common consequence of UV-induced degradation in polymers.
In summary, the UV-Vis spectroscopy results clearly indicate that exposure to UV radiation has a significant impact on the stability of PE and PP. These changes in optical properties, including increased absorbance, reduced transmittance, and discoloration, provide evidence of UV-induced discoloration, provide evidence of UV-induced degradation. Understanding these UV stability characteristics is essential for industries that rely on these polymers for outdoor applications, enabling them to implement protective measures or choose alternative materials to ensure the longevity and performance of their products.

Chemical Stability (FTIR Analysis)
Examination of Chemical Resistance:
Polyethylene (PE) and polypropylene (PP) find applications in a wide range of industries, often coming into contact with various chemicals, including acids, bases, solvents, and reactive substances. Understanding the chemical stability and resistance of these polymers is crucial to ensure their performance and longevity in specific environments.

To evaluate the chemical resistance of PE and PP, a series of exposure tests were conducted, subjecting specimens of both polymers to different chemical solutions representative of real-world scenarios. These solutions included acids with varying concentrations, bases, common solvents, and other chemicals relevant to specific industry applications. The samples were exposed to these chemicals for predetermined durations.

An FTIR peak represents the absorption of infrared radiation at specific wavelengths or wavenumbers by chemical bonds and molecular vibrations within a sample. FTIR is a widely used analytical technique for identifying and characterizing organic and inorganic compounds based on their unique infrared absorption patterns. As new chemical bonds arise or break, the absorption of radiation tends to vary.

The FTIR analysis of PE and PP exposed to various chemicals revealed notable observations:

1.New Peaks: In some cases, the emergence of new peaks in the FTIR spectra indicated the formation of new chemical bonds or functional groups. This suggests that chemical reactions occurred between the polymer and the test chemicals.

2. Chemical Bonds and Functional Groups: Different types of chemical bonds (e.g., C-H, O-H, C=O) and functional groups (e.g., alkanes, alkenes, carbonyls) have characteristic FTIR absorption frequencies. As a result, the presence of specific bonds or functional groups can be identified by the positions of the absorption peaks in the FTIR spectrum.

3. Peak Intensity: The intensity of an FTIR peak represents the strength of the absorption at a particular wavelength. Stronger peaks indicate higher absorption, which can correlate with the concentration of the chemical species responsible for the absorption.

4. Peak Shape: The shape of an FTIR peak can provide information about the environment and symmetry of the vibrational mode. Simple, sharp peaks may indicate well-defined vibrations, while broad or complex peaks can suggest interactions or multiple vibrational modes occurring simultaneously.
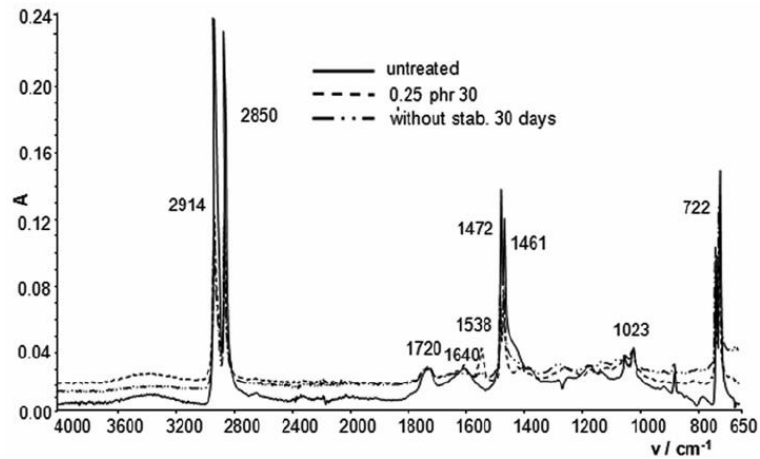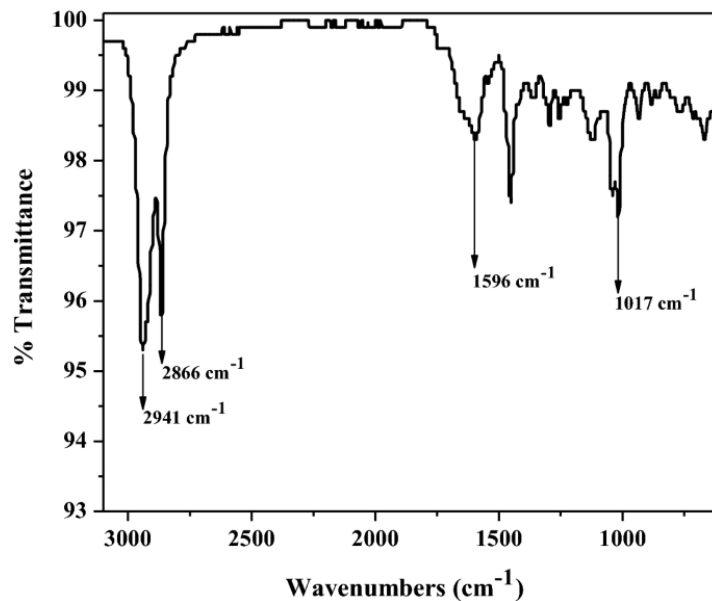

Fig.4: A FTIR spectroscopic analysis of HDPE

A FTIR spectroscopic analysis of iPP

V. LIMITATIONS

1. Data Source Limitation: All data was obtained from Alok Masterbatches, limiting the generalizability of the findings to other sources.

2. Reliance on Pre-existing Data: The study primarily relied on preexisting data from Alok Masterbatches, with only select tests (TGA and FTIR) repeated for verification, introducing minute variations (within the limitations for variation values)

3. Limited Instrument Accuracy: There is a possibility that the accuracy of the instruments used in data collection may vary, potentially affecting the precision of the results.

4. Single Data Source: Data obtained exclusively from Alok Masterbatches may introduce bias and limit the diversity of materials and sources considered.

5. Lack of Real-Time Data: The study does not incorporate real-time data collection, potentially missing dynamic changes in stability over time.

6. External Environmental Factors: The study does not account for external environmental factors that could influence the stability of PE and PP under different conditions.

7. Sample Size Variation: Variations in sample sizes for different tests may introduce inconsistencies in data analysis.

8. Potential Data Gaps: Given the reliance on existing data, there may be missing or unreported variables that could impact the comprehensiveness of the analysis.

VI. REFERENCES

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