

Comparative studies (using FTIR) of structural changes in HDPE under UV aging for different commercial companies

O. Zhouri ¹, I. Haddouch ¹, Z. Mouallif ², I. Mouallif  ¹ ✉

¹ Moulay Ismail University of Meknes, Meknes, Morocco

² Université Hassan 1^{er}, Settat, Morocco

✉ i.mouallif@ensam.umi.ac.ma

Abstract. One of the key pillars of the nation's infrastructure is the sewerage system. The selection of sewerage pipelines must therefore be done after extensive research before they are installed in the relevant network. These studies should guarantee the durability of these pipelines. High density polyethylene is produced due to its dominance in these applications. But despite the performance of the latter, it can be attacked by chemical or physical factors. Our research aims to analyze HDPE samples that have been exposed to ultraviolet (UV) rays from natural light for predetermined amounts of time using infrared spectroscopy. The structural alterations of the chemical bonds in these samples' composition can be determined by FTIR spectroscopy analysis. The results show that there is a remarkable change in the spectra of the aged (after exposure) and unaged (before exposure) samples.

Keywords: HDPE, FTIR, UV, chemical structure, degradation, polymer

Citation: Zhouri O, Haddouch I, Mouallif Z, Mouallif I. Comparative studies (using FTIR) of structural changes in HDPE under UV aging for different commercial companies. *Materials Physics and Mechanics*. 2023;51(2): 122-127. DOI: 10.18149/MPM.5122023_11.

Introduction

Today, polymer is widely employed in the production of sewer pipes, and it takes many various forms: Polyvinyl Chloride (PVC), Polypropylene (PP), High Density Polyethylene (HDPE), and Glass Fiber Reinforced Polyester (GFRP) [1-3]. This material is known for its durability, simplicity of installation and economic efficiency. All of these materials are susceptible to degradation in a variety of chemical and physical methods: attack by water's acidity, failure by the high temperature, mechanical stress, and photo-oxidation by UV rays [4-7].

We may point to some literature evaluation that looked at how the mechanical and structural characteristics of polymers behaved when subjected to various aging processes. N. Guermazi [8] examined how mechanical and structural qualities changed by the effect of time and temperature aging. This study demonstrated that both the structural change (as determined by FTIR spectroscopy analysis) and the mechanical properties were affected by aging damage (tensile tests).

T. Lu [9] provides a numerical simulation model of the damage caused by ultraviolet radiation (by varying: wavelength, intensity and exposure time) to polymer surfaces (flat and sinusoidal), as well as an experimental test of the exposure of epoxy samples to UV in high temperature (80 °C) air. The results of this work show a decrease in the surface roughness of the aged specimens.

When L. Douminge [10] used fluorescence spectroscopy to analyze the behavior of high-density polyethylene under ultraviolet irradiation or mechanical solicitation, the results revealed a very high sensitivity to the microscopic events intervening at the first moments of UV radiation exposure.

Karla I. Martínez carried out a degradation study by infrared spectroscopy of polyethylene films of three different types: low density polyethylene (LDPE), high-density polyethylene (HDPE) and biodegradable polyethylene (BIO-PE), exposure to UV radiation at a variety of time intervals [11]. These samples were also exposed to domestic composting during two different seasons (spring and fall) under ambient conditions.

I. Mouallif used infrared spectroscopy to examine how HDPE's structural changes, moisture absorption, and modification in mechanical characteristics changed when subjected to sulfuric acid aging at different temperatures [12-14]. They studied the phenomena of absorption, which enabled water to diffuse into HDPE samples and impact the material's mechanical and structural properties.

The logical conclusion is that in order to completely eliminate the possibility of environmental damage, the sanitation material must be chosen after a number of tests. Therefore, the purpose of this paper is to compare samples of HDPE pipes that have been subjected to degradation by UV radiation from natural light using FTIR spectroscopy.

Method

Preparation of samples. Four national firms that produce and distribute these pipes on an industrial scale have allowed us to collect samples of HDPE (high density polyethylene) pipes of different diameters.

The samples were sliced into little pieces, or pellets, each measuring 1 cm in diameter as shown in Fig. 1., using a screwdriver (in order to be compatible with the analysis tank of the FTIR apparatus).



Fig. 1. The pellets of the samples to be analyzed (measuring 1cm in diameter)

Aging of samples. The samples were exposed to natural UV light for different periods. Each sample was used in three different states: virgin state, aged for 77 days, aged for 131 days. In total, 12 samples were examined.

Infrared spectroscopy. The type of instrument used for this study is VERTEX 70v FT-IR spectrometer. The infrared spectroscopy was performed with a resolution of 4 cm^{-1} , in the range of $4000\text{ to }500\text{ cm}^{-1}$. The HDPE samples were examined at a mirror speed of 0.4747 utilizing a KBr separator and a DTGS ATR detector because of their robust nature.

Results and discussions

The measurement of the FTIR spectrum using the transmission mode was done to determine the structural characteristics of the aged material [15-17]. The Figs. 2-5 correspond to the infrared spectra of the different samples. Three spectra of one product are shown in each figure, and each spectrum represents one of the following states:

- Spectrum 1: virgin state (no aging process);
- Spectrum 2: aged for 77 days;
- Spectrum 3: aged for 131 days.

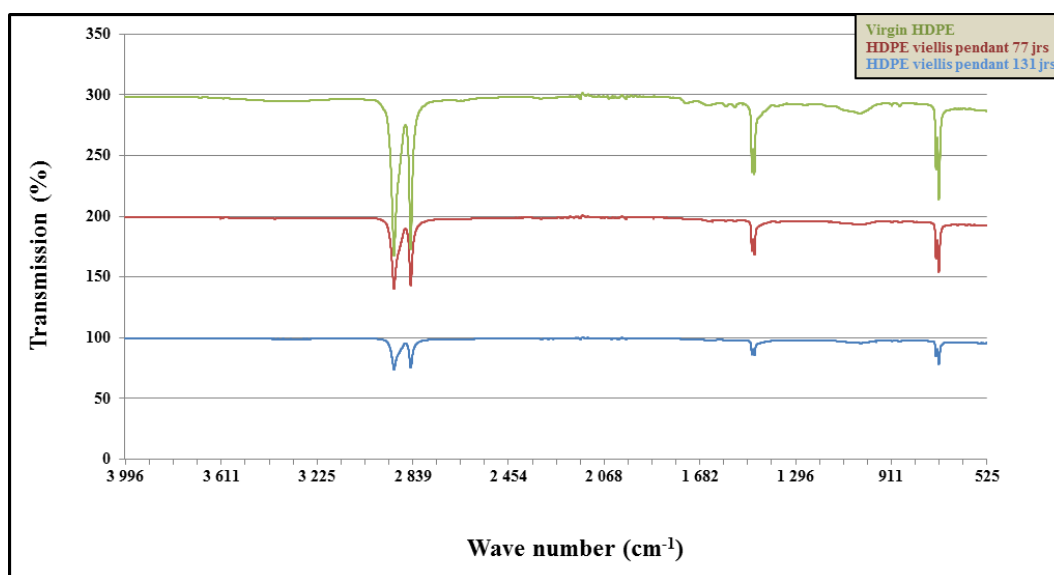


Fig. 2. HDPE spectra acquired by the transmission mode. Unaged and aged samples for 77 days and 131 days. IR spectra of samples from the 1st manufacturer (P)

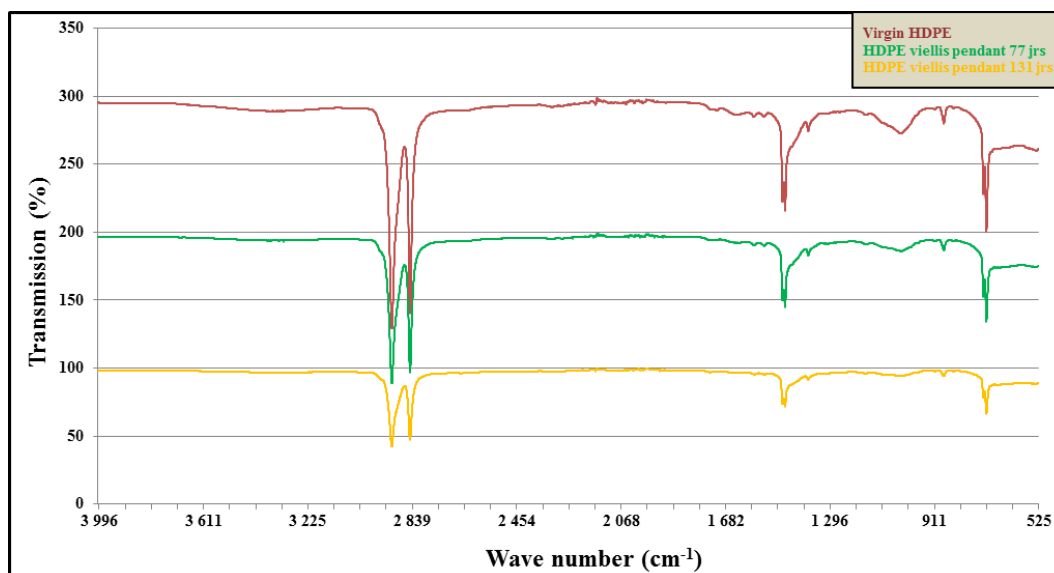


Fig. 3. HDPE spectra acquired by the transmission mode. Unaged and aged samples for 77 days and 131 days. IR spectra of samples from the 2nd manufacturer (F)

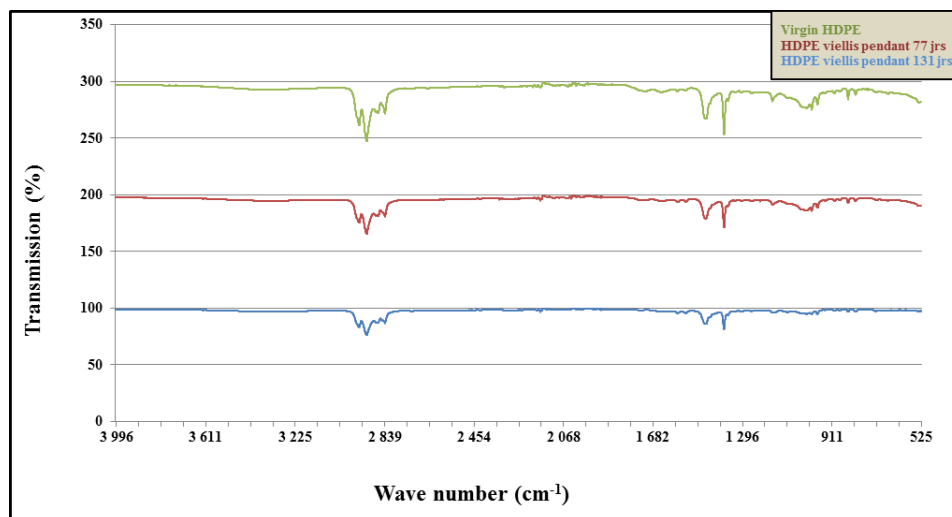


Fig. 4. HDPE spectra acquired by the transmission mode. Unaged and aged samples for 77 days and 131 days. IR spectra of samples from the 3rd manufacturer (D)

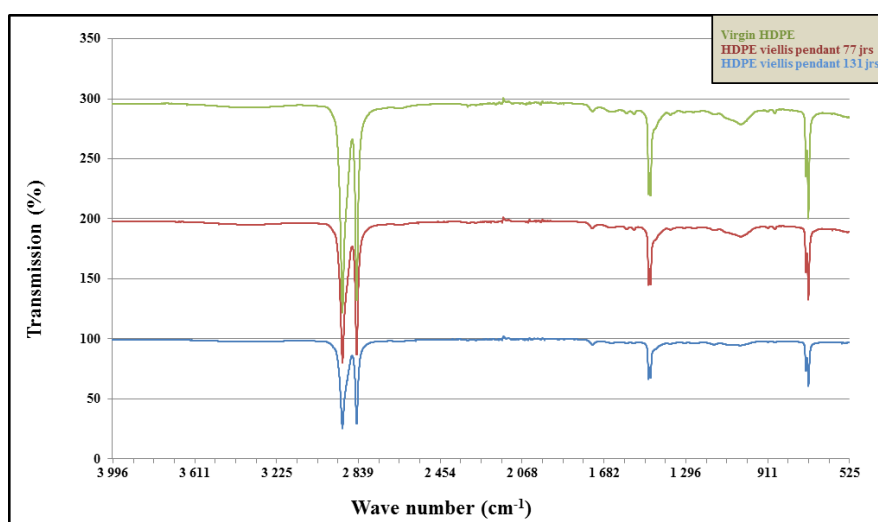


Fig. 5. HDPE spectra acquired by the transmission mode. Unaged and aged samples for 77 days and 131 days. IR spectra of samples from the 4th manufacturer (I)

By using FTIR spectroscopy, we attempted to examine the structural changes of HDPE samples from different manufacturers (P, F, D, I).

Fig. 2. shows the IR spectrum of the 1st sample. Its primary bands are situated at (2914 and 2847) cm^{-1} : a strong peak that reflects the CH₂ group being stretched asymmetrically; (1471 and 1462) cm^{-1} : Average peak, which reflects bending deformation, (717 and 730) cm^{-1} : an average peak, results of the aromatic C-H group being deformed.

Fig. 3. depicts the IR spectrum of the 2nd sample. Its primary bands are situated at (2914 - 2847) cm^{-1} : A fine and strong that reflects the CH₂ group being stretched asymmetrically; (1472 - 1462) cm^{-1} : a medium peak, corresponds to bending-induced deformation; (718 - 730) cm^{-1} : medium peak, that is caused by the aromatic C-H group deformation.

Fig. 4. shows the IR spectrum of the 3rd sample. Its primary bands are situated at (2914 - 2847) cm^{-1} : a strong peak that reflects the CH₂ group being stretched asymmetrically, (1472 - 1462) cm^{-1} : a medium peak, which corresponds to a deformation by bending, 1376 cm^{-1} : a strong peak, which corresponds to a deformation of CH₃ bond, (1540 - 1737) cm^{-1} : 4 bands indicating an elongation, of the aromatic C-C bond.

The fourth product's IR spectrum is depicted in Fig.5. Its primary bands are situated at (2914 - 2847) cm^{-1} : a strong peak reflects the CH₂ group being stretched asymmetrically; (1471 - 1462) cm^{-1} : average peak, corresponds to bending deformation, (717 - 730) cm^{-1} : Average peak, corresponds to an aromatic C-H group deformation [18-20].

As shown in Table 1, we have tried to include the main chemical bonds of the studied HDPE samples.

Table 1. Main bands of FTIR spectra of HDPE studied

Wavelength, cm^{-1}	Functional group	Vibration type	References
730-717	Aromatic C-H	Deformation	[11,14,18]
1462-1472	-CH ₂ -	Elongation	[14,18,19]
2914	CH ₂ et CH ₃	Elongation	[11,14,16]

We can clearly demonstrate whether there is in fact a structural modification induced by the UV aging process by analyzing the infrared spectra of the material. As can be observed, all four samples show the same transmission bands. The only difference between the four samples' transmission bands is their intensity. This difference can be seen in the decrease of the signal intensity of the following bands (corresponding to 2900, 1570, 1460 cm^{-1} , etc.). This indicates the beginning of the disappearance of these bands. In all four cases, the change in intensity can be taken as evidence of the beginnings of polymer chain scission and breakdown, which cause structural alterations in the UV-exposed products that persist 77 days at 131.

Conclusion

According to this study, HDPE deteriorates when exposed to UV rays from natural daylight. The examined FTIR spectra revealed significant variations in the transmission bands. We can speculate that these changes are caused by the onset of chemical bond breakdown and the amorphization of polymeric chains because they manifest as a drop in band intensity as a function of aging time. The findings of this study enabled us to draw the conclusion that exposure to UV causes HDPE's chemical structure to deteriorate. So, it may be said that in order to ensure a long service life, HDPE pipes shouldn't be progressively exposed to natural light before being laid.

References

1. Alabtah FG, Mahdi E, Eliyan FF. The use of fiber reinforced polymeric composites in pipelines: A review. *Composites Structures*. 2021;226: 114-595.
2. Nguyen KQ, Mwiseneza C, Mohamed K, Cousin P, Robert M, Benmokrane B. Long-term testing methods for HDPE pipe – advantages and disadvantages: A review. *Engineering Fracture Mechanics*. 2021;246: 107-629.
3. Birer O, Suzer S, Sevil UA, Guven O. UV-Vis, IR and XPS analysis of UV induced changes in PVC composites. *Journal of Molecular Structure*. 1999;482-483: 515-518.
4. Chudnovsky A, Zhou Z, Zhang H, Sehanobish K. Lifetime assessment of engineering thermoplastics. *International Journal of Engineering Science*. 2012;59: 108-139.
5. Contino M, Andena L, Rink M, Marra G, Resta S. Time-temperature equivalence in environmental stress cracking of high-density polyethylene. *Engineering Fracture Mechanics*. 2018;203: 32-43.
6. Khan IA, Lee KH, Lee YS, Kim JO. Degradation analysis of polymeric pipe materials used for water supply systems under various disinfectant conditions. *Chemosphere*. 2022;291:

132669.

7. Petukhova ES, Fedorov AL. IR spectroscopy research of the influence of UV radiation on stabilized polyethylene composites. *Procedia Structural Integrity*. 2020;30: 105-112.
8. Guermazi N, Elleuch K, Ayedi HF. The effect of time and aging temperature on structural and mechanical properties of pipeline coating. *Materials and Design*. 2009;30: 2006-2010.
9. Lu T, Solis-Ramos E, Yi Y, Kumosa M. UV degradation model for polymers and polymer matrix composites. *Polymer Degradation and Stability*. 2018;154: 203-210.
10. Douminge L. Study of the behavior of high density polyethylene under ultraviolet irradiation or mechanical stress by fluorescence spectroscopy. In: *Laboratory for the Study of Materials in Aggressive Environments*. Université de la Rochelle; 2010.
11. Martinez KI, Gonzalez-Mota R, Soto-Bernal JJ. Evaluation by IR spectroscopy of the degradation of different types of commercial polyethylene exposed to UV radiation and domestic compost in ambient condition. *Applied Polymer Science*. 2020;138: 50158.
12. Mouallif I, Latrach A, Chergui M, Hangouët JP, Barbe N. Degradation of dynamic mechanical properties of glass fiber reinforced polyester composite pipes after immersion in various temperatures. *Journal of Composite Materials*. 2013;48: 3025–3034.
13. Lasfar S, Moualli FI, Latrach A, Choukir A, Diab A. Resistance of two different types of concrete pipes used in sewer systems under sulfuric acid and sodium sulfate attacks. *Journal of Materials and Environmental Science*. 2015; 3002–3014.
14. Mouallif I, Latrach A, Chergui M, Benali A, Barbe N. FTIR study of HDPE structural changes, moisture absorption and mechanical properties variation when exposed to sulphuric acid aging in various temperatures. In: *20ème Congrès Français de Mécanique*. Besançon, France; 2011. p.hal-03420950.
15. Carrasco F, Pagès P, Pascal S, Colom X. Artificiel aging of high-density polyethylene by ultraviolet irradiation. *European Polymer Journal*. 2001;37: 1457-1464.
16. Mizushima M, Kawamura T, Takahashi K, Nitta K. In situ near-infrared spectroscopic studies of the structural changes of polyethylene during melting. *Polymer Journal*. 2012;44: 162-166.
17. Yu W, Azhdar B, Andersson D, Reitberger T, Hassinen J, Hjertberg T, Gedde UW. Deterioration of polyethylene pipes exposed to water containing chlorine dioxide. *Polymer Degradation and Stability*. 2011;96: 790-797.
18. R. Chandra, Renu Rustgi. Biodegradation of maleated linear low-density polyethylene and starch blends. *Polymer Degradation and Stability*. 1996;56: 185-202.
19. Domenech SC, Severgnini VLS, Pinheiro EA, Avila AOV, Borges Jr NG, Lima Jr E, Drago V, Soldi V. Effect of chemical surface treatment on thermal stability of polyethylene terephthalate) films used in flexible circuits. *Polymer Degradation and Stability*. 2005;88: 461-467.
20. Boudrahem M, Belbah A, Kirati O. Etude de vieillissement d'un polyethylene de haute densité (PEHD 100) utilisé dans les conduites à gaz sous pressions. *Journals of Materials, Process and Environnement*. 2014;2: 20-26.

THE AUTHORS

O. Zhouri

e-mail: oumaima-zh@hotmail.com

Z. Mouallif

e-mail: mouallifzakaria@gmail.com

I. Haddouch

e-mail: winnerhaddouch@gmail.com

I. Mouallif 

e-mail: i.mouallif@ensam.umi.ac.ma