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UV Irradiation Exposure of Polymer Composite Filled with Recycled Unused Diapers

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Abstract: The objective of this study was to investigate the problem of environmental pollution caused by discarded diapers. This was achieved by developing and examining a polymer composite material that incorporated recycled unused diapers (RD) along with Polypropylene (PP) and Polyethylene, using different proportions. The mechanical properties of the specimens were evaluated through the conduction of tensile testing and Shore D hardness testing, both before and after exposure to UV irradiation at a predetermined time and temperature. Surface fractures were observed using optical microscope analysis following exposure to UV irradiation. Through a comprehensive understanding of the impacts of ultraviolet (UV) exposure, it is possible to gain insights into the potential utilization of discarded diapers in the development of composite materials. This innovative approach has the capacity to effectively mitigate the issue of diaper waste pollution while simultaneously promoting sustainable waste management practices.

Keywords: Discarded Diapers, Polypropylene, Polyethylene, Mechanical Properties, Tensile Testing, Shore D Hardness Testing, UV Irradiation, Surface Fractures, Optical Microscope Analysis, Ultraviolet Exposure, Utilization Composite Materials.

1. Introduction

Polypropylene (PP) is a commercially available plastic that has gained significant popularity since its discovery in 1954. It is characterized by its low density and is produced through a catalytic process using propylene. PP is highly sought after due to its exceptional processability, resistance to chemicals, and ability to act as a moisture barrier. Consequently, it finds widespread applications in various industries such as automotive, cosmetics, textiles, and consumer packaging. In fact, polypropylene represents approximately 25 percent of the global polymer demand [1]. Polypropylene (PP) stands out as the lightest among commonly used plastics due to its low density. By decreasing the density of the plastic, it becomes possible to produce a larger number of components from the same quantity of plastic material. In comparison to polyethylene, the distinction in density between crystalline and amorphous

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regions is minimal. Nevertheless, the incorporation of additives can significantly modify the density of polyethylene [2]. Polypropylene (PP) is a thermoplastic material that is semi-crystalline and viscoelastic. It is produced by polymerizing propylene molecules. When used in applications at room temperature, PP demonstrates excellent physical, mechanical, and thermal properties [3]. It is relatively rigid and has a high melting point of 130℃, with a crystalline melting point range of 160-170℃. PP also possesses strong impact resistance, as well as high fatigue resistance, chemical resistance, environmental stress cracking resistance, detergent resistance, and hardness [4].

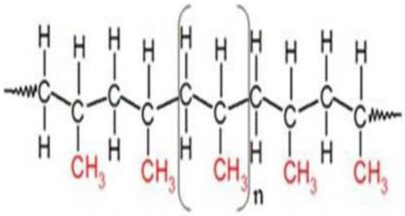

Figure 1: Molecular Structure of Polypropylene

Polyethylene, with its chemical formula [CH2-CH2], is a polymer made up of ethylene monomers, forming long-chain structures. It is available in different forms such as HDPE, LDPE, and LLDPE (Figure 1). Polyethylene is produced through the chemical process of ethane polymerization, and its properties can be modified by introducing various side chains during manufacturing. The backbone of polyethylene solely consists of C-C single bonds, making it highly resistant to hydrolysis. As a result, polyethylene is considered one of the most chemically inert polyolefins. In terms of mechanical properties, polyethylene exhibits relatively low strength, limited creep resistance, modest tensile strength, and good impact resistance. The impact strength ranking is as follows: HDPE < LLDPE < LDPE [4]. Polyethylene exhibits insolubility in common solvents at temperatures below 60 ℃. However, prolonged exposure to halogenated hydrocarbons, aromatic hydrocarbons, or aliphatic hydrocarbons can lead to a degradation in its performance. When the temperature surpasses 60 ℃, polyethylene can undergo partial dissolution in organic solvents such as trichloroethylene, toluene, paraffin, or mineral oil [5].

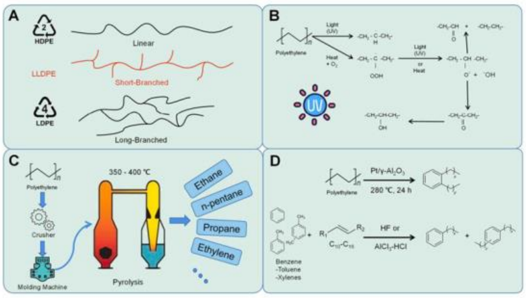

Figure 2: Classification of polyethylene and schematic diagrams representing the common traditional methods for polyethylene degradation.

In the past, parents commonly fashioned diapers from natural materials like animal skins and milkweed leaf wraps, utilizing whatever resources were accessible. The commercialization of diapers gained momentum in the early 1900s with the introduction of cloth diaper services. The historical practice of employing cotton and linen for diaper purposes can be traced back to the 1800s [6]. Disposable diapers are a common choice in today's culture. It is projected that more than 95% of diapering babies use disposable diapers, with an average consumption of 5,000 to 7,500 diapers before toilet training [7] Disposable diapers generate an enormous quantity of environmental trash [8]. Used diapers are rich in a variety of useful components, including polymers, fibers, and cellulose pulp, which may be separated out of the diapers and used as raw materials in the manufacturing of other goods [9]. Currently, only a limited number of European countries, namely England, Italy, and the Netherlands, possess the required technology for recycling used diapers. One notable innovation, developed by Knowaste Ltd. and currently implemented in the UK, involves a series of steps. These steps encompass shredding the diapers, subjecting them to agitation with a chemical salt serving as a drying agent, autoclaving the material, and selectively separating it into plastic and fiber components [10]. Discarded diapers can be a valuable source of salvageable materials such as plastics, fibers, and cellulose pulp. These materials can be effectively repurposed and utilized in the production of new items [11]

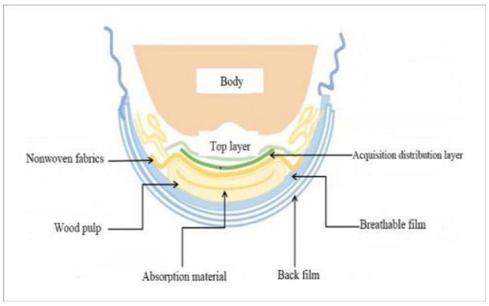

Figure 3: Structure of a disposable diapers

2. Materials and Methods

The initial step depicted at the uppermost section of a flowchart commences at the inception point, after the completion of the research phase and the subsequent formulation of the remaining components of the study. The initial stage of this investigation involves the determination of the minimum required specimen mass through the process of weighing different ratios. Subsequently, the specimen will be conveyed to the polymer workshop, wherein an injection moulding machine will be employed to shape the specimen into the desired configuration. Consequently, an investigation will be undertaken to examine the impact of UV irradiation exposure on the specimen.

2.1 Materials

The experimental materials employed in this study consist of polypropylene, polyethylene, and recycled unused diapers, all of which are obtained from the Sustainable Polymer Engineering (SPEN) laboratory. The Sustainable Polymer Engineering (SPEN) lab serves as the main provider of materials for this project.

2.2 Methods

Materials Preparation

A precision weighing scale is employed for the purpose of quantifying the relative proportions of polypropylene, polyethylene, and recycled unused diapers. The specimens that have been weighed are thoroughly mixed within a container. The proportions of polypropylene (PP) and polyethylene (PE) are marginally greater in comparison to the proportion of waste diapers (WD). The specimen ratio and weight are presented in Table 1 and Table 2.

Table 1: The composition ratio of the PP and WD

Sample	Materials	
	Polypropylene (PP)	**Recycled Diapers (RD**
PP	$100\%(200g)$	-
$PD5$	$95\%(190g)$	$5\%(10g)$
$PD10$	$90\%(180g)$	$10\%(20g)$
$PD15$	$85\%(170g)$	$15\%(30g)$
$PD20$	$80\%(160g)$	$20\%(40g)$
$PD25$	$75\%(150g)$	$25\%(50g))$

Table 2: The composition of PE and WD

Sample	Materials	
	Polyethylene (PE)	Recycled Diapers (RD
PE	$100\%(200g)$	-
PED_5	$95\%(190g)$	$5\%(10g)$
PED_{10}	$90\%(180g)$	$10\%(20g)$
PED_{15}	$85\%(170g)$	$15\%(30g)$
PED_{20}	$80\%(160g)$	$20\%(40g)$
PED_{25}	$75\%(150g)$	$25\%(50g)$

Injection Molding

The injection molding process involves the melting of pallets or granules of raw material within a barrel, followed by the injection of the molten material into a mold to achieve the desired shape. The specimen was fabricated through the process of injection molding, employing the specific parameters outlined in Table 3. The appropriate parameters were determined by analyzing the mechanical characteristics of polypropylene and polyethylene. The parameters have been thoroughly analysed and, as per the guidance and recommendations offered by polymer laboratory technicians, appropriate modifications have been implemented.

Table 3: Injection Molding Parameters

Parameter	Nozzle	Middle	Front	Rear 1	Rear 2	Feeds
Temperature	195℃	180℃	190℃	170℃	175℃	50℃
Injection Pressure	50%					
Injection Rate	50%					
Inject time	6.5s					
Cooling time	40.0s					

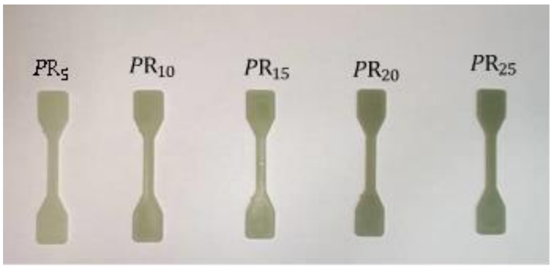

Figure 5: Specimens produced with appropriate parameters.

UV Accelerated Weathering Tester

The experimental procedure involves the utilization of a UV accelerated weathering tester to expose specimens to UV irradiation subsequent to the injection molding procedure. The objective of this research is to replicate the impact of sunlight has on the polymer composite mixed with waste diapers. By replicating the spectrum and intensity of UV radiation, the tester allows manufacturers to evaluate potential degradation and changes that occur over extended periods in a shorter timeframe. The tester uses UV lamps emitting UV-A and UV-B light, like natural sunlight. Test specimens are placed in the chamber and exposed to controlled UV radiation while monitoring parameters like UV intensity, temperature, and humidity. The results provide valuable information about a material's resistance to fading, discoloration, embrittlement, cracking, and peeling caused by UV exposure.

Tensile Testing

The tensile testing procedure employed in this study utilized the Autograph Universal Testing Machine AGS - 5kNJ, manufactured by Shimadzu (Asia Pacific) Pvt. Ltd., Singapore. The specimens are subjected to tensile testing both prior to and following exposure to UV irradiation in order to assess the stress and strain characteristics of the specimens.

Figure 6: Universal testing machine

Shore D Hardness Testing

The hardness of specimens composed of polyethylene and polypropylene mixed with sawdust was measured using the Shore D hardness tester in this study. The specimens underwent UV irradiation both prior to and subsequent to the injection molding procedure, employing varying proportions of the waste diapers composite. The hardness evaluation was conducted using the Shore D hardness test, which involves the application of force to the surface of the material and subsequent measurement of the resulting indentation. The evaluation of the material's hardness properties was facilitated by comparing the hardness values prior to and subsequent to UV exposure, thereby enabling an assessment of the influence of UV radiation on said properties. The hardness measurements exhibited variability in relation to the ratios of the sawdust composite, thus suggesting that the composition exerted an influence on the hardness of the specimens. The examination of the hardness data, taking into account the composite ratios and UV irradiation, yielded significant findings regarding the collective impact of these variables on the overall hardness of the materials.

Optical Microscopy Analysis

Optical microscopy is employed for the examination of surface fractures in specimens with varying composition ratios subsequent to UV irradiation analysis. The examination of the fracture surface allows for the identification of different types of fractures, including brittle fractures, ductile fractures, and highly ductile fractures. From this analysis, it is possible to determine whether the specimens exhibit high stress or low stress, as well as high strain or low strain. The specimens are analysed using the Olympus SZH10 optical microscope. The product incorporates a zoom design that enables users to flexibly adjust the levels of magnification. The device is outfitted with optics and illumination systems of superior quality, which guarantee the production of precise and elaborate images of the specimens under examination. The examination of the morphology of the fractured surfaces of the specimens holds significant importance in comprehending the effects of photodegradation, mechanical properties, and material homogeneity.

Figure 7: Olympus SZH10 Optical Microscope

3. Results and Discussion

Tensile Test Results for PP_{100} and PD before UV Irradiation Exposure

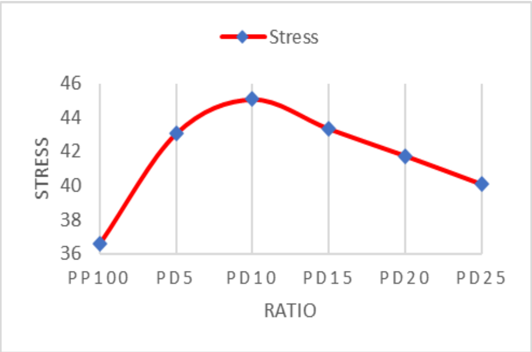

Figure 8: Stress vs ratio for PP_{100} and PD.

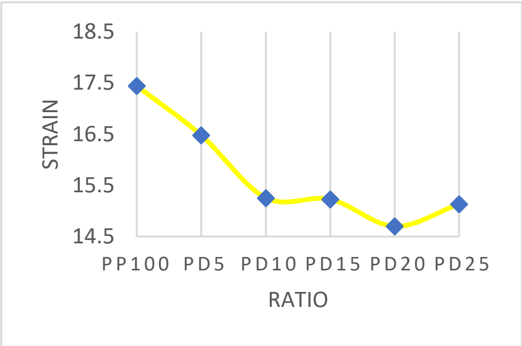

Figure 9: Strain vs ratio for PP_{100} and PD.

Based on the data presented in Figure 8, it is evident that the composition ratio PD_{10} demonstrates the highest stress value of 45.0593 N/mm² before UV irradiation. Conversely, the minimum stress value is observed in PP_{100}. These findings suggest that incorporating waste diapers in the sample mixture positively affects the material's strength, while pure polypropylene (PP) exhibits relatively lower strength. Therefore, the inclusion of waste diapers in a material has the potential to enhance its mechanical properties. According to the data presented in Figure 9, PP_{100} exhibits the maximum strain value, indicating higher extensibility or elongation compared to other materials. In contrast, PD_{20}demonstrates the lowest strain value, suggesting reduced stretchability or flexibility due to the presence of waste diaper contents. Unlike the stress values observed in Figure 8, it is observed that the stress value of PD_{20} is relatively higher than that of pure polypropylene. This suggests that PD_{20} exhibits brittle behavior while still being capable of withstanding significant stress levels.

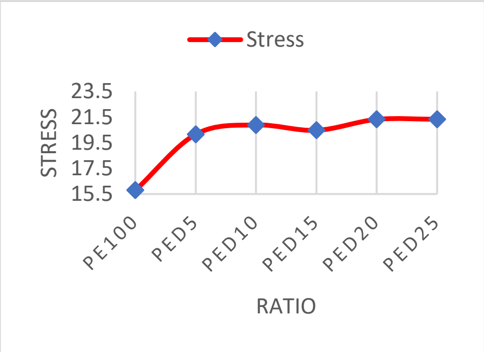

Figure 10: Stress vs ratio for PE_{100} and PED.

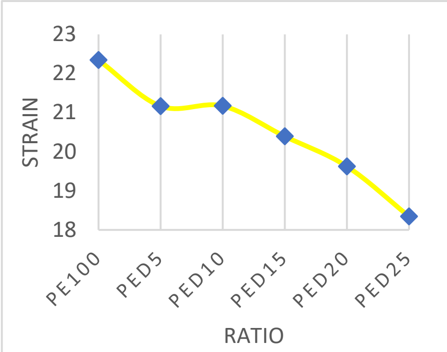

Figure 11: Strain vs ratio for PE_{100} and PED.

Figure 10 illustrates the relationship between applied stress and the proportion of samples containing a mixture of waste diapers. According to the data presented, the composition ratio PD_{25} exhibits the highest stress value of 21.3299 N/mm², indicating a significant influence of waste diaper composition on stress tolerance. Pure Polyethylene, in contrast, demonstrates a stress value of 15.7998 N/mm². The findings in Figure 4.1 further support these observations, as the maximum stress value is observed at the PD_{10} ratio (45.0593 N/mm²), indicating favorable results when incorporating polypropylene with waste diapers. However, it is important to note that pure polypropylene and polyethylene exhibit the lowest stress levels before UV irradiation.

Figure 11 presents the correlation between the composition ratio and the strain or elongation capacity of the material. The data indicates that pure polyethylene exhibits the highest strain value of 22.3397, while the composition ratio of PD_{25} demonstrates the lowest strain value of 18.3469. This inverse relationship suggests that a higher content of waste diapers in the material reduces its elongation capacity, while a lower content allows for greater elongation. This indicates that materials experiencing high levels of stress exhibit relatively low levels of strain, whereas materials subjected to low levels of stress tend to exhibit higher levels of strain.

Tensile Test Result for PD at different ratios after UV Irradiation Exposure at 50℃, 60℃, 70℃ over the duration of 5 hours.

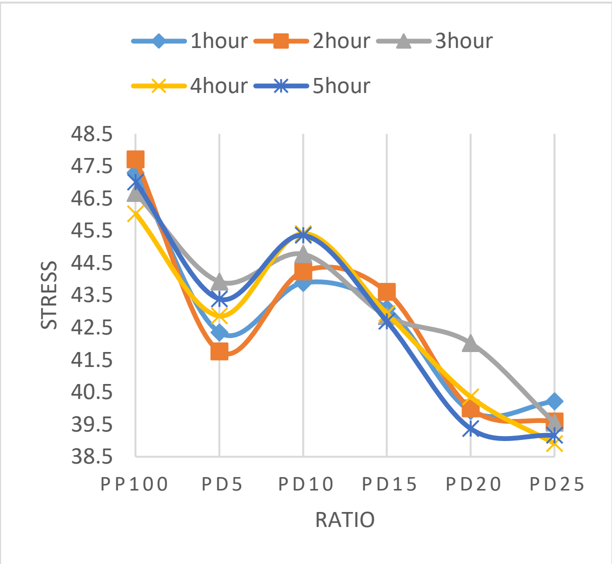

Figure 12: The average stress vs ratio for PD at 50℃ UV Irradiation Exposure.

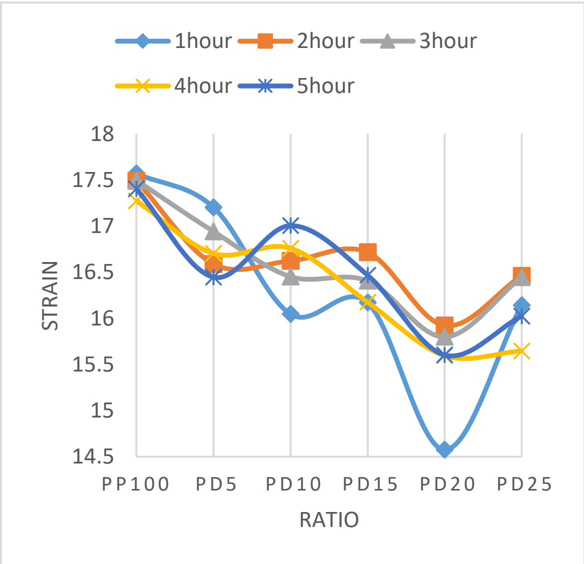

Figure 13: The average strain vs ratio for PD at 50℃ UV Irradiation Exposure.

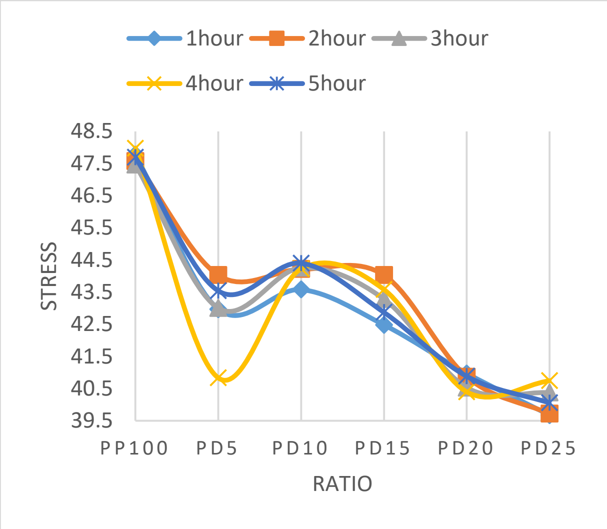

Figure 14: The average stress vs ratio for *PD* at 60℃ UV Irradiation Exposure.

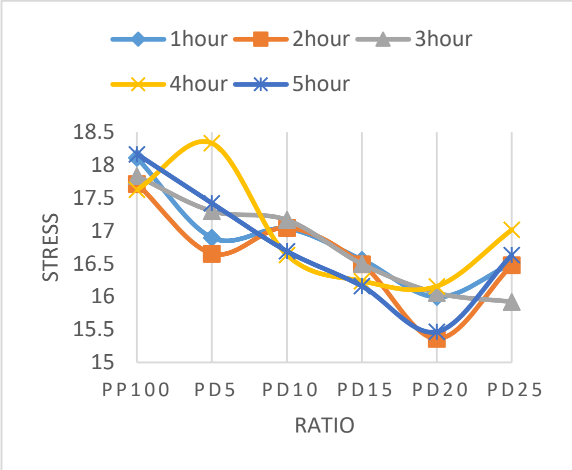

Figure 15: The average strain vs ratio for *PD* at 60℃ UV irradiation Exposure.

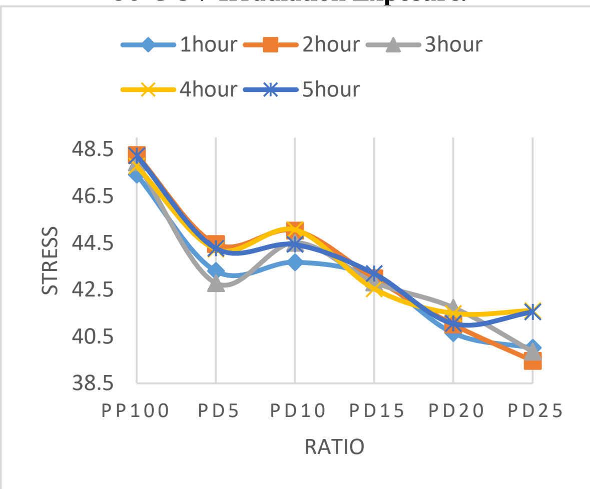

Figure 16: The average stress vs ratio for *PD* at 70℃ UV Irradiation Exposure.

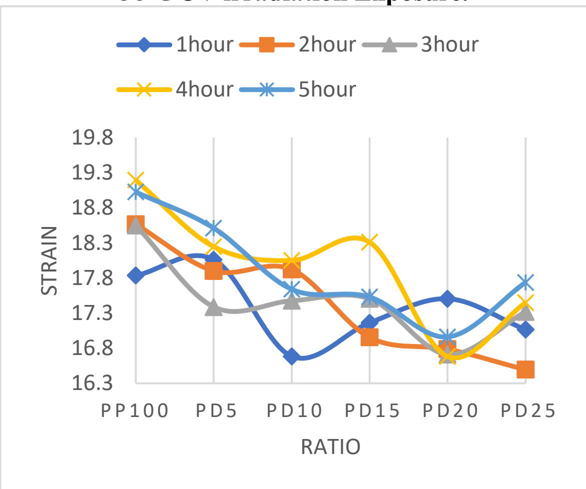

Figure 17: The average strain vs ratio for *PD* at 70℃ UV Irradiation Exposure.

Figures 12, 14, and 16 depict the correlation between stress and the composition ratio of the specimen's following exposure to UV irradiation at temperatures of 50°C, 60°C, and 70°C, respectively, for durations ranging from 1 to 5 hours. The composition ratio of PD_{25} exhibits the lowest stress value following UV irradiation within the time range of 1 to 5 hours. The findings indicate that specimens with a high concentration of waste diapers exhibit reduced strength. It is noteworthy to mention that the composition ratio PD_{10} exhibits the second highest stress value. However, as the ratio increases, the specimens' ability to endure stress diminishes.

Figures 13, 15, and 17 illustrate the relationship between strain and the composition ratio of the specimen subsequent to its exposure to UV irradiation at temperatures of 50°C, 60°C, and 70°C, correspondingly, for varying durations spanning from 1 to 5 hours. The majority of the elevated stress levels are observed in pure polypropylene. The composition ratio of of PD_{20} exhibits the lowest level of stress. Based on the data, it can be inferred that the presence of waste diapers in the specimens leads to a decrease in their stretching or elongation capacity.

Tensile Test Result for PED at different ratios after UV Irradiation Exposure at 50℃, 60℃, 70℃ over the duration of 5 hours.

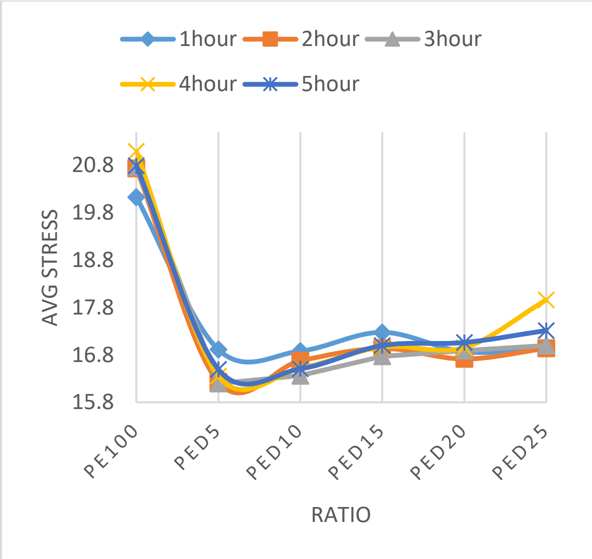

Figure 18: The average stress vs ratio for *PED* at 50℃ UV Irradiation Exposure

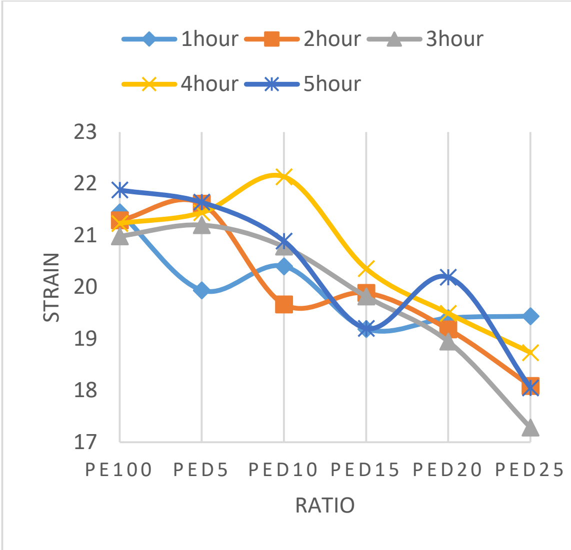

Figure 19: The average strain vs time for *PED* at 50℃ UV Irradiation Exposure

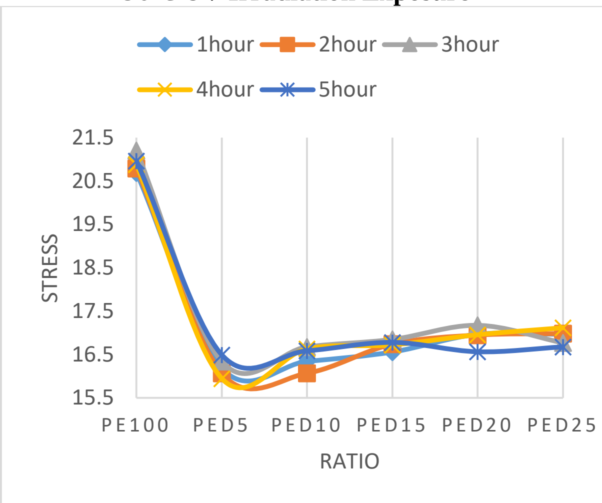

Figure 20: The average stress vs ratio for *PED* at 60℃ UV Irradiation Exposure

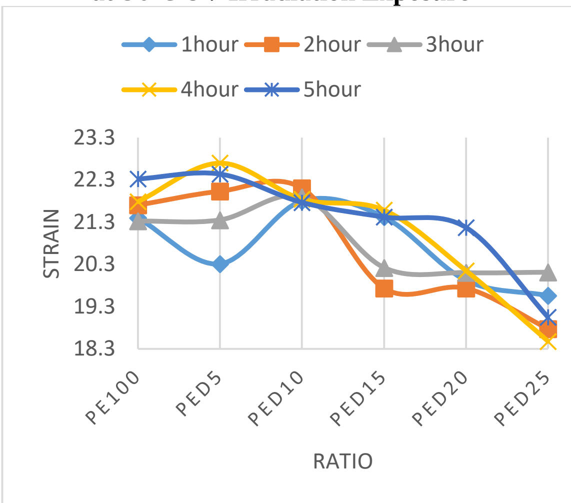

Figure 21: The average strain vs ratio for *PED* at 60℃ UV Irradiation Exposure

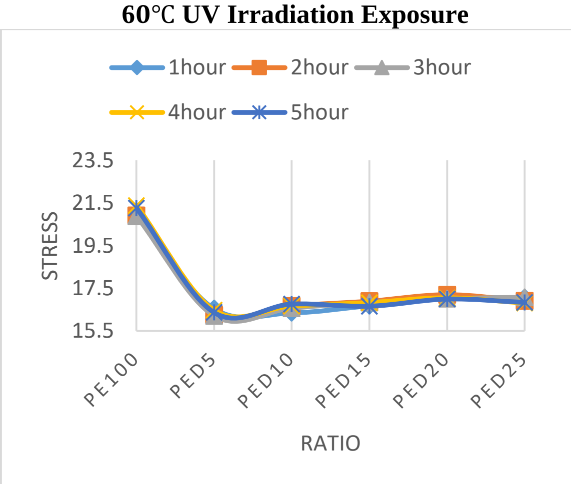

Figure 22: The average stress vs ratio for *PED* at 70℃ UV Irradiation Exposure

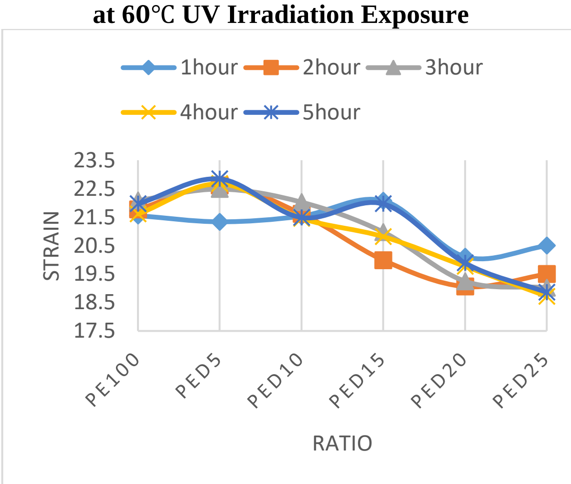

Figure 23: The average strain vs ratio for *PED* at 70℃ UV Irradiation Exposure

According to the data presented in Figures 18, 20, and 22, it is evident that the pure polyethylene samples exhibit the highest stress values. The stress value gradually decreases as the composition ratio of PED_5increases in waste diapers, and then slowly increases as the composition ratio reaches PED_{25}. This observation indicates that increased concentrations of waste diapers have a beneficial effect on the material's strength, albeit not to the same extent as pure polyethylene.

The data presented in Figures 19, 21, and 23 consistently indicate that pure polyethylene samples demonstrate the highest strain values. As the content of waste diapers in the specimens increases, there is a gradual decrease in the strain values observed. This observation suggests that the inclusion of waste diapers in the material composition has an impact on its ability to stretch or deform under applied forces. The decreasing trend in strain values with increasing waste diaper content implies that the specimens containing a higher proportion of waste diapers exhibit reduced flexibility or elongation capacity compared to pure polyethylene. This could be attributed to several factors, such as the presence of additional components in waste diapers that may restrict the material's ability to stretch, or the altered structural properties introduced by the waste diaper materials.

Shore D Hardness test before UV Irradiation Exposure

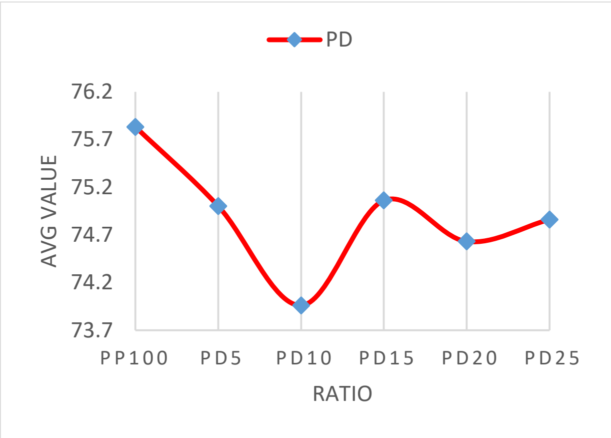

Figure 24: Shore D hardness for PD before UV irradiation

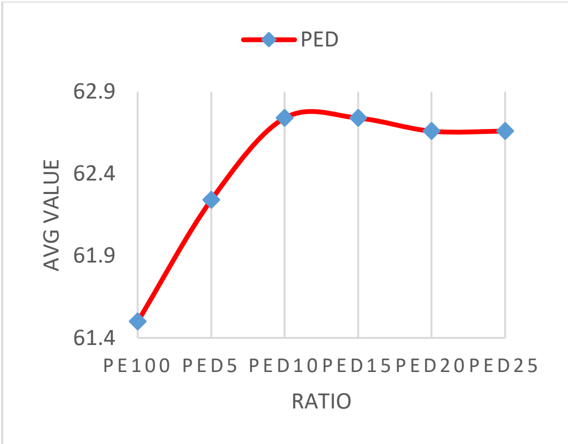

Figure 25: Shore D hardness for PED before UV irradiation

Based on the data presented in Figure 24, the analysis reveals notable differences in hardness values among the various compositions of polypropylene (PP). Pure polypropylene exhibits the highest hardness value, measuring at 75.83, while the composition ratio of PD_{10} demonstrates the lowest hardness value of 73.96. These findings indicate that the presence of additives or fillers, as represented by the composition ratios, influences the hardness of polypropylene.

According to the data presented in Figure 4.47, it is evident that the composition ratio of PED_{10} and PED_{15} exhibits the highest hardness value of 62.74. In contrast, it is observed that pure polyethylene exhibits the lowest level of hardness, measuring at 61.5. This observation demonstrates that the inclusion of waste diapers in the composition of a material has a beneficial effect on its hardness.

Shore D Hardness Test Results Polypropylene mixed waste diapers (PD) after UV Irradiation.

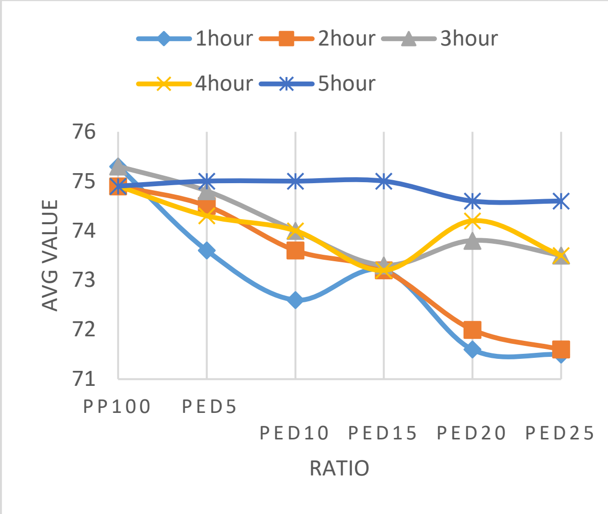

Figure 26: Average Shore D hardness for PD after UV irradiation at 50℃ for the duration of 1 to 5hours.

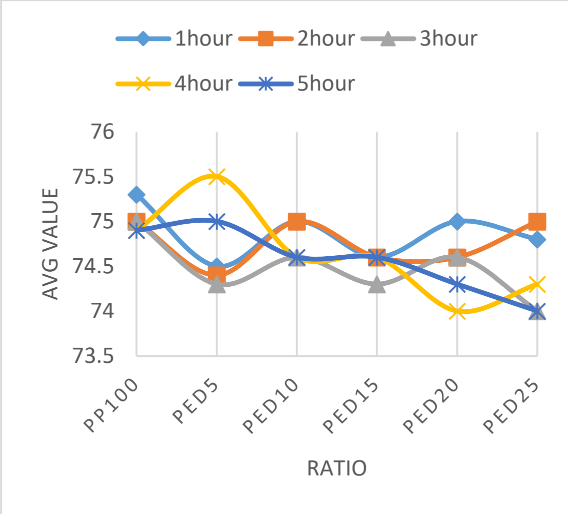

Figure 27: Average Shore D hardness for PD after UV irradiation at 60℃ for the duration of 1 to 5hours.

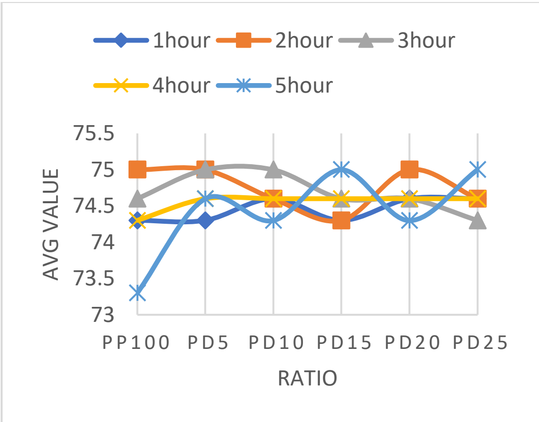

Figure 28: Average Shore D hardness for PD after UV irradiation at 70℃ for the duration of 1 to 5hours.

Based on the analysis of Figure 26, 27, and 28, it can be deduced that the exposure of PD compositions to UV irradiation at temperatures of 50℃, 60℃, and 70℃ resulted in negligible effects on their hardness properties. The tested materials exhibited a significant capacity to resist indentation and retained their inherent hardness properties throughout the duration of the experiment. The hardness is affected by the exposure to UV irradiation, albeit to a minimal extent.

Shore D Hardness Test Results Polypropylene mixed waste diapers (PED) after UV Irradiation.

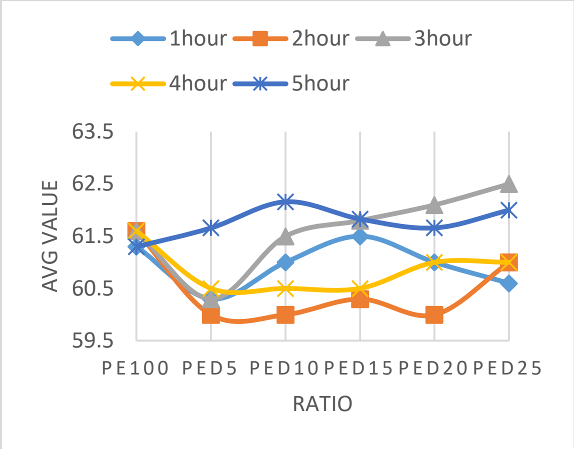

Figure 29: Average Shore D hardness for PED after UV irradiation at 50℃ for the duration of 1 to 5 hours.

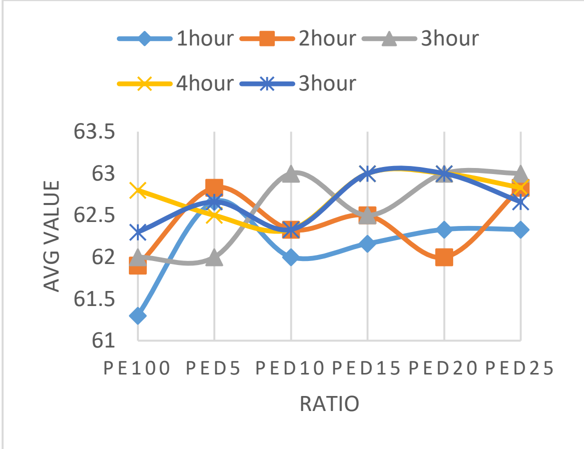

Figure 30: Average Shore D hardness for PED after UV irradiation at 60°C for the duration of 1 to 5 hours.

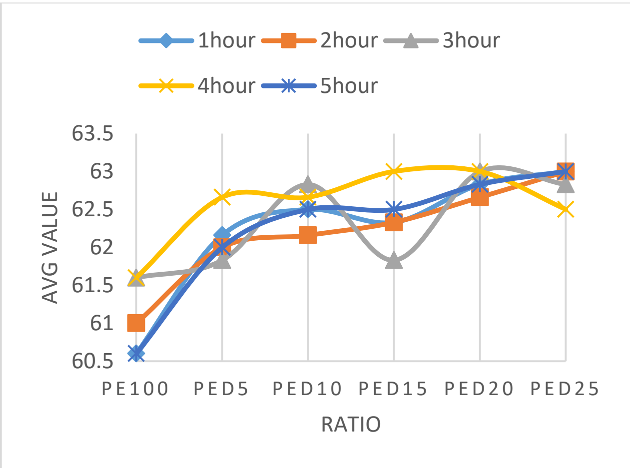

Figure 31: Average Shore D hardness for PED after UV irradiation at 70°C for the duration of 1 to 5 hours

Based on the examination of Figure 29, 30, and 31, it can be inferred that subjecting PED compositions to UV irradiation at temperatures of 50°C, 60°C, and 70°C had minimal impact on their hardness characteristics. The materials that were subjected to testing demonstrated a notable ability to withstand indentation and maintained their inherent hardness characteristics throughout the entirety of the experimental period. The hardness of the material is influenced by its exposure to ultraviolet (UV) irradiation, albeit to a negligible degree. However, it can be observed that the hardness of the material undergoes only slight changes depending on the duration of exposure to UV irradiation.

4. Conclusion

In summary, this study successfully achieved its objectives of creating polymer composites through injection molding by incorporating discarded diapers with polypropylene (PP) and polyethylene (PE) at different ratios. The mechanical properties of these composites were also investigated under UV irradiation. The research demonstrates the feasibility of integrating waste diapers and polymers to produce environmentally sustainable composites. Furthermore, the examination of mechanical characteristics provides valuable insights into the behavior of these composites when exposed to UV radiation. The findings contribute to the understanding of degradation mechanisms and the suitability of the composites for outdoor applications. Overall, this study contributes to the advancement of composite materials and the efficient utilization of waste materials, while considering their response to UV radiation**.**

Acknowledgement

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References

[1] Wang, X., Han, X., Xu, R., 2020. Versatile Propylene-Based Polyolefins with Tunable Molecular Structure through Tailor-Made Catalysts and Polymerization Process. Intech Open, London.

[2] Tripathi, D. (2001). Practical guide to polypropylene. Shrewsbury: RAPRA Technology. ISBN 978-1859572825.

[3] H. Karian, Handbook of PolyproN. Pasquini and A. Addeo, Polypropylene Hanse

[4] J. U. Duncombe, "Infrared navigation - Part I: An assessment of feasibility," IEEE Trans. Electron. Devices, vol. ED-11, pp. 34-39, Jan. 1959. (Example for a journal article)

[5] H. Karian, Handbook of PolyproN. Pasquini and A. Addeo, Polypropylene Hanse

[6] A. Altun, "Understanding hypertext in the context of reading on the web: Language learners' experience," Current Issues in Education, vol. 6, no. 12, July 2003. [Online]. Available: http://cie.ed.asu.edu/volume6/number12/. [Accessed Dec. 2, 2004].

[7] L. Liu and H. Miao, "A specification-based approach to testing polymorphic attributes," in Formal Methods and Software Engineering: Proceedings of the 6th International Conference on Formal Engineering Methods, ICFEM 2004, Seattle, WA, USA, November 8-12, 2004, J. Davies, W. Schulte, M. Barnett, Eds. Berlin: Springer, 2004. pp. 306-19.

[8] Lauren, A., Lawrence, F., 2014. Diapering habits: a global perspective. Pediatr. Dermatol. 31(1), 15–18

[9] Khoo, S.C., Phang, X.Y., Ng, C.M., Lim, K.L., Lam, S.S., Ma, N.L., 2019. Recent technologies for treatment and recycling of used disposable baby diapers. Process Saf. Environ. Prot. 123, 116–129.

[10] Knowaste, 2021. Knowaste technologies - home [WWW document]. URL https://www.knowaste.com/ (accessed 12.1.23).

[11] J. P. Wilkinson, “Nonlinear resonant circuit devices,” U.S. Patent 3 624 125, July 16, 1990.

[12] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.

[13] J. O. Williams, “Narrow-band analyzer,” PhD dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, 1993.