

Effect of Fillers on Mechanical, Thermal Properties and Combustion Resistance of Polyurethane Foam

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ABSTRACT

In this study, the mechanical and combustion properties of a polyurethane polymer were investigated as a function of the weight ratio of palm frond ash with a particle volume less than or equal to (125 μm). Several variables were investigated, including elongation, tensile strength, Young's modulus, compressive strength, and rate of burning duration. The obtained results revealed that adding palm frond ash reduces the spaces between the polymeric chains, which reflect the polymer's high ability to withstand the stress imposed on it, that the degree of homogeneity between each of the polymers and fillings is high. Results showed that adding 60% palm frond ash powder to the hardness combination resulted in an improvement of approximately (3.78 MPa). Moreover, the percentage 65% was recorded as the greatest value of the compressive strength of the polymer with the additive. Young's modulus also best value is (1.71 MPa) at a ratio of 60%.

Keywords: palm frond ash; polyurethane; thermal properties; mechanical properties; fire retardant

INTRODUCTION

The reaction results in the production of polyurethane insulation material, a compound made up of polyol and isocyanate. It is better to use polyurethane to insulate the walls of cold stores in order to lower the thickness of the thermal insulation because this material has a connectivity factor that is smaller than that of polystyrene. The standard acronym for polyurethane is (PU), and it is used as insulation to provide durability and protection for objects it covers from heat, cold, and wear from frequent use. Products made of polyurethane foam play a significant role in the industry, particularly in the areas of thermal and acoustic insulation, and this is because due to its cellular structure, it differs from many other polymeric materials and has a low heat conductivity compared to other insulation materials [1]. Since the Inflexible PU foam's hardness rises with density, foam with better properties is produced. More specifically, an increase in density of (1000 g/cm^3) suggests an increase in hardness of approximately (100 Pa)[2].

Currently, polyurethane is widely used in several industries, including construction, packaging, and furniture. The remainder of the polyol chain, which is flexible, and hydrogen bonds, which are rigid, make up polyurethane[3]. Calcium carbonates, mica, and talc are examples of some inorganic fillers materials that are more commonly used with polymers, while fiber materials like glass, aramid, and natural fibers for carbon fiber are frequently used as reinforcement additives with polymers. Fillers materials used with polymers are divided into natural (organic and inorganic) and synthetic fillers. These fillers, the majority of which are inorganic and either fibers or particles, are combined with polymers to both increase their hardness and lower their price [4–7].

The natural fibers are an excellent filler to combine with polymer matrix for reinforcement additives such as, date palm tree's fibers are utilized as sawdust or burned to keep insects away for space recovery [8–9]. In our earlier research, we examined the impact of palm ash addition on the mechanical properties of high density polyethylene (HDPE). To the best of our knowledge, no research has been done on modifying ash from palm frond fillers with polyurethane polymers in order to decrease flammability [10]. Additionally, the effect of ash from palm fronds powder on the mechanical properties of low-density polyethylene (LDPE) was investigated. At a specific size of 75 μm , several variables, including maximum stress, Young's modulus, proportional limit, maximum strength, and elongation, were investigated [11].

The results of this investigation by Atiqah et al. [12] show that the composites' mechanical and thermal properties have improved. The ideal values for the composite formulation with a 40 weight percent sugar palm fiber loading were 17.22 MPa for tensile strength, 13.96 MPa for flexural strength, and 15.47 kJ/m^2 for impact strength. The mechanical and thermal characteristics of polyurethane polymer composites with waste additives were examined in the current study (Ash of Palm Fronds). The goal of this study was to determine how fire retardants, mechanical qualities, and thermal properties affected the filler composition of ash from palm fronds.

MATERIALS, METHODS AND FILLERS

Polyurethane was used as the foundation material in this investigation. The two materials (polyol and isocyanate) are in the liquid state, and gas is released as a result of this reaction, carbon dioxide, which works to form cellular spaces within the mass of the mixture.

As a result of the mixing process, a so-called foamy liquid emulsion is formed that responds under the influence of the gas result. Polyurethane is prepared as an insulating material through the chemical reaction shown in Figure 1.

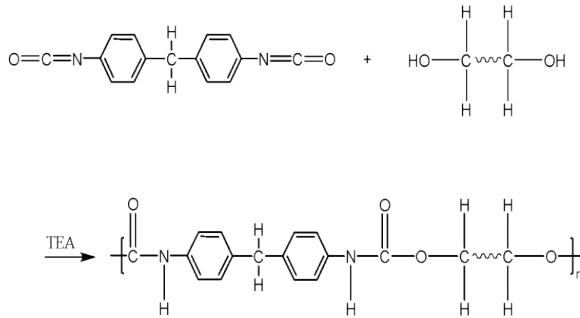


FIGURE 1: Chemical composition of polyurethane.

Since it falls under the category of natural fillers, Basrah-Iraqi palm frond ash has been employed; this substance has a hardness, strength, and a variety of components, proteins, and others, which are among the characteristics that set it apart from other fillers as polymer fillers. It was created by air-burning dried palm fronds completely. After passing through an Allen-Bradley Sonic Sifter Model L3P wire sieve to produce an ultrafine powder with fine-grained consistency and a particle size of at least 125 μm , provided by ATM Corp. American, The palm fronds and their ash are seen in Figure 2.



FIGURE 2: A photograph showing palm fronds ash.

By adding several weight ratios (50%, 55%, 60%, 65%, 70 and 75%) of palm fronds ash to the polymer mixture during the polymerization procedures, the samples of polyurethane and palm fronds ash were created. Until the mixture was homogeneous, the mixing operation was maintained. The finished product was then put into a slab mold with a cylindrical shape. The measurements of the cylindrical form samples for stress are 3 cm in length and 1 cm in diameter, the dimensions of the cylindrical form samples for tensile and bending are 11 cm in length and 1 cm in diameter (see Figure 3).

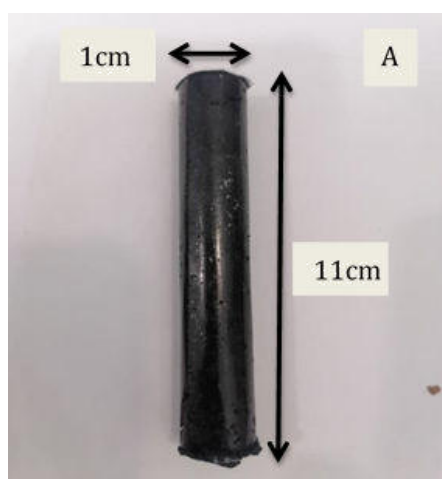


FIGURE 3: A and B the cylindrical samples.

CHARACTERIZATION

The samples created for this study are judged using the following tools:

First:- a German-made (Tensile) equipment was used to test the models' tensile strength, bending resistance, and compression resistance. The mechanical properties measurement instrument is shown in figure (4), and equation (1) is used to compute the tensile strength.

$$Q = F / A \text{ (N / mm}^2\text{)}$$

F is the cutting force (Newton), and A is the cross-sectional area (mm^2).

The following relationship was used to compute the Young modulus using the stress-strain curves:

$$\text{(Young's modulus) } Y = (\text{Max Stress/Max Strain}) \text{ (Mpa)}.$$

Second:- the burning rate for each of the manufactured samples was calculated using a combustion rate measurement instrument, Average Time of Burning ATB [11], in accordance with the industry standard method 81 ASTM D635. For each sample, the measurement was made three times, and the results were averaged. The time it took to burn the model to a distance of (75 mm) was calculated.

Third:- The FTIR (infrared thermal imaging) was recorded (as KBr discs) on a Japanese-made JASCO FTIR 4100 equipment with a wavenumber range of (400–4000) cm^{-1} . The straightforward method of infrared spectroscopy revealed details on the material's structure and chemical bonds.

RESULTS AND DISCUSSION

• Average Time of Burning (ATB)

Flame retardants have gained a lot of attention recently, particularly in the field of applied polymers, and may have the ability to shorten the burning period of flammable materials. The physical and chemical pathways make up the two primary parts of the fire retardant mechanism[13]. The current study examines the impact of palm frond ash fillers on the rate of polyurethane burning time. Figure (4) shows the relationship between the weight ratios of the filler content and the average burning time. Increased filler ratios resulted in a faster rate of polymer burning time, which was plainly seen at higher concentrations (approximately 289 seconds for %75).

From a physical standpoint, the ash layer that has formed on the polymer's surface functions as an insulating layer on the surface, stopping the spread of flame inside the polymeric matrix. Unlike non-additives(0%),

polymer burned at 60 seconds. The percentage change in burning time was calculated by dividing the difference between the percentage's values for the impure and pure states by the percentage's value for the pure state, as shown in Figure 5, The burning time percentage is equal to $A - B / B * 100\%$.

A: The fillers' weight in relation to the polymer's, B: The polymer's weight ratio in its purest form. Where we notice from the figure below that this behavior of polymer is attributed to the low decomposition of palm fronds ash at High ratios confined between (50%-75%) and thus reduce the process of heat spread within the polymeric matrix by reducing the total volume of the combustible polymer, a process known as thermal insulation between the burned parts and the unburned parts and thus prevents the spread of flame within the polymer chains, Especially when the weight ratio(75%).

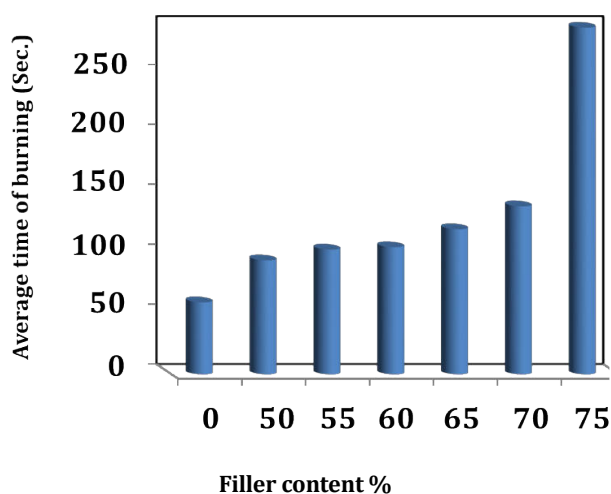


FIGURE 4: Relationship between the average time of burning with the concentration of palm frond ash additive to the polyurethane polymer.

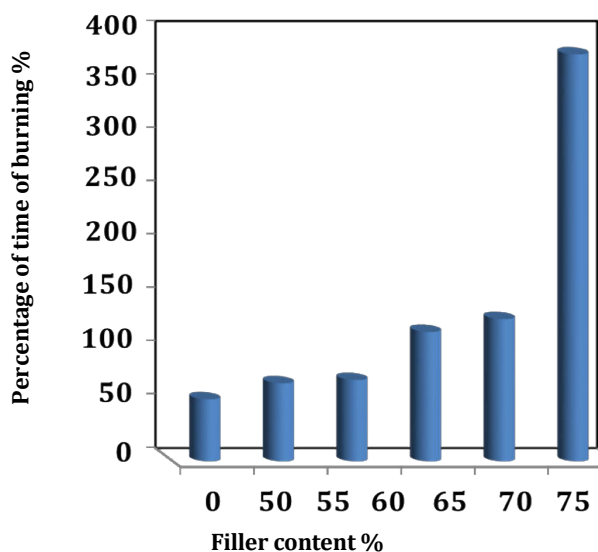


FIGURE 5: The relationship between the percentage of burning time and the concentration of the additive palm frond ash for a polyurethane polymer.

• Mechanical properties

Figure 6, depicts the relationship between bending resistance and additive percentage. The pure polymer exhibits bending resistance of (12.6 Mpa), meaning that it is more elastic than the other samples but less rigid. Lower flexibility and higher hardness are caused by the rigid filler, which restricts the mobility of the polymer chains[14]. This discovery is readily apparent at ratio%60, when there is high compatibility between the chains of the filler and the polymer. Nonetheless, the additive particles dispersed uniformly as the percentage of additives increased.

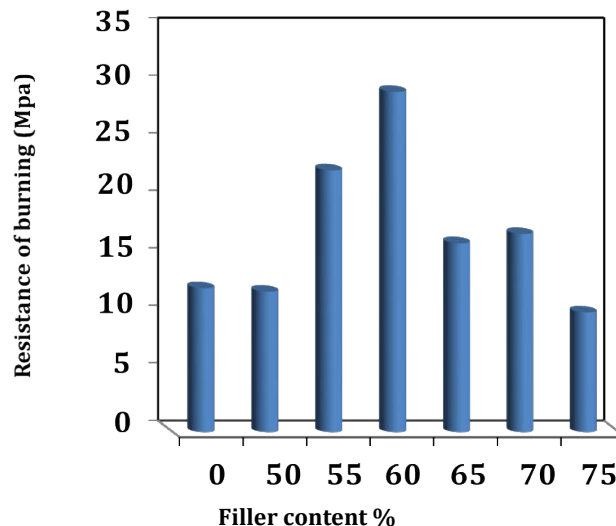


FIGURE 6: The relation between the bending resistance and the filler content.

Figure 7, shows the effect of ash of palm frond powder affects compressive coefficient, which is a measure of a material's capacity to withstand compressive pressures acting perpendicularly on solid materials. While the compressive modulus at 65% is at its highest value (10.7 Mpa), the compressive modulus at 0% is noticeably low, close to (4.5 Mpa). It has led to the realization that the additive, through a homogeneous interphase with the polymeric chains, imposes on the polymer's hardness. However, the behavior of the polymer begins to decline at high percentages of the additive, especially at the percentage 75%, where the compressive strength was recorded by (6.8 Mpa). It may attribute to excesses bubbles formation which make walls easier to collapse.

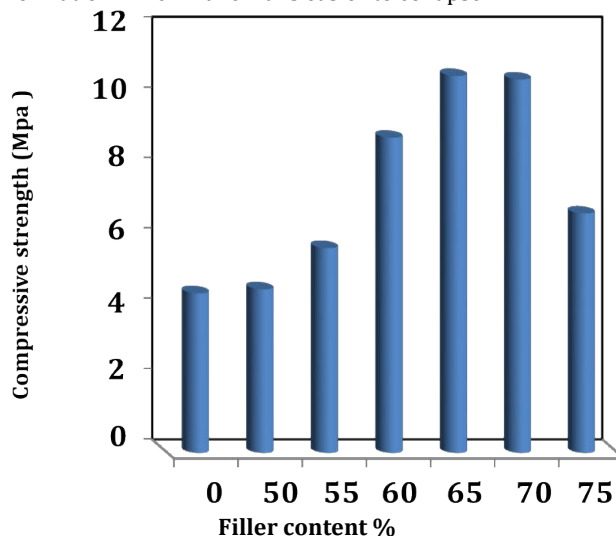


FIGURE 7: The relation between the compressive strength and the filler content.

The relationship between the tensile force (stress force) and the proportion of the polymeric additives is depicted in Figure 8. At lower filler content levels as low as ratio (50%), there was a modest reduction in tensile strength, however at higher filler content levels from ratio (60%), the maximum strength is comparable to that of pure polymer. This is because the additive powder is distributed uniformly throughout the polymeric chains. However, the maximum strength rapidly decreases with greater percentages. The ratio (60%) of the powder additive was best for the mixture's hardness, which is estimated to be (3.78 MPa).

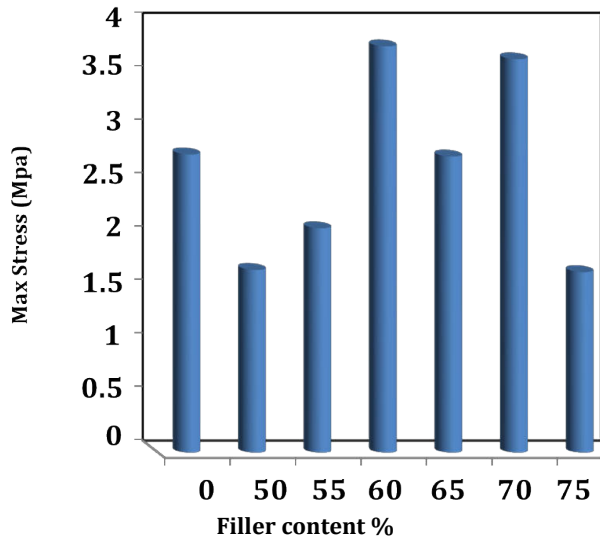


FIGURE 8: The relation between tensile strength and the filler content.

Figure 9, shows the polymer elongation model with concentration. With rising ash percentages, the effect of filler addition on the polymer's elongation % became less pronounced. The elongation reduced as the polymer filler concentration rose because the particles filled the gaps between the polymeric chains, preventing and restricting the mobility of those chains. The ratio (0%) is best for the polymer's elasticity, while the lowest value of elongation is (1 MPa) at the ratio (75%).

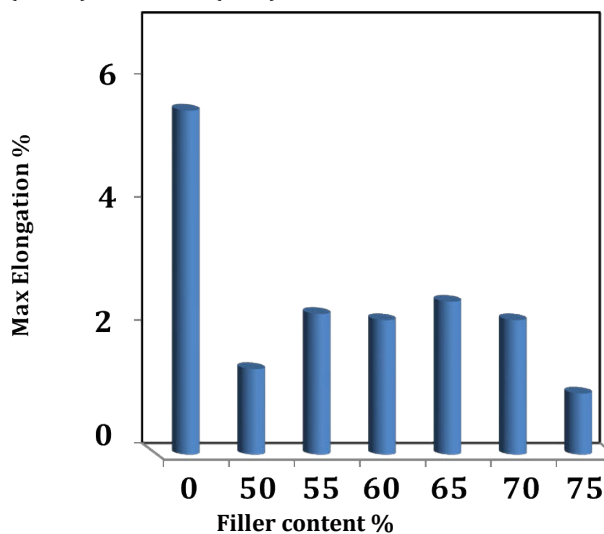


FIGURE 9: The relation between elongation and the filler content.

Figure 10, illustrates how palm frond ash powder affects the Young modulus, which is the ratio of stress to strain for solids only and is defined as the elasticity modulus. In general, adding more filler had a beneficial effect on the elasticity modulus.

Elasticity would be decreased while homogeneity would be increased since the powder increases the polymer's hardness, and perhaps the decrease in the Young modulus is explained by the ratio between (65%) for the additive to the heterogeneity of the mixture, despite the fact that the samples were mixed in the same conditions, this indicates that the polymer has high elasticity, that is, the polymer chains are not restricted to a certain ratio and the stiffness is low at this ratio, that is, it is free to move, and these results are consistent with many other pieces of research in this field.

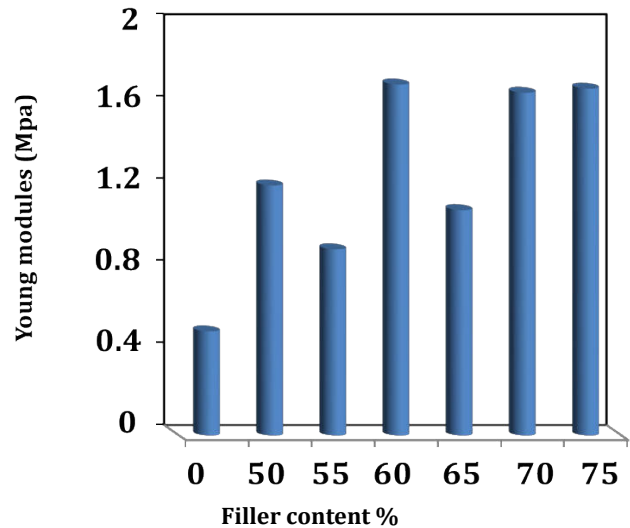


FIGURE 10: The relation between Young's modulus and the filler content.

CONCLUSIONS

We conclude that adding ash powder to polyurethane has a significant impact on the mechanical properties. The ratio (60%) of the powder additive was best for the mixture's hardness, which is estimated to be (3.78 MPa), while the ratio (0%) is best for the polymer's elasticity. Additionally, the greatest value of Young's modulus (1.71 MPa) was recorded at the ratio (60%). We draw the conclusion from this study that the average burning time of a polymer containing an additive behaves in a manner consistent with an increase in the percentage of the additive, which ranges from 50 to 75%, as it recorded the highest value of the average burning time (289 Sec.) at the percentage (75%).

REFERENCES

- [1] Nasser Haj Hussein "Improving the Properties of Polyurethane to be Used in Thermal Insulation Purposes", Master Thesis ,faculty of mechanical engineering- department of power-university of Aleppo, Syria (2018).
- [2] Irene Izarra , A.M. Borreguero , I. Garrido , J.F. Rodríguez a, M. Carmona," Comparison of flexible polyurethane foams properties from different polymer polyether polyols", Polymer Testing 100 (2021) 107268.
- [3] Sylwia Członka, Agne Kairyte, Karolina Miedzińska and Anna Strąkowska," Polyurethane Composites Reinforced with Walnut Shell Filler Treated with Perlite, Montmorillonite and Halloysite", Int. J. Mol. Sci. (2021), 22, 7304. <https://doi.org/10.3390/ijms22147304>.
- [4] Duluth. M.N, Plastics Compounding Red Book. Edgell Communications, (2001), Vol. 24
- [5] Ceresana, Market Study: Fillers (3rd edition); (2014).

- [6] Tariq Syed, Abdul Salam Thelakkadan, Saad Al-Hussain," Date-Palm Fiber as a Reinforcement Filler in Polymer Composites", *Advances in Sciences and Engineering* 2020;12(2):78-85, doi.org/10.32732/ase.2020.12.2.78.
- [7] Xanthos. M, *Functional Fillers for Plastics*. Wenham: WILEY-VCH; (2010).
- [8] Oushabi A, Sair S, Hassani FO, Abboud Y, Tanane O, El Bouari A. The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): Study of the interface of DPF Polyurethane composite. *S. Afr. J. Chem. Eng.* 2017; 23: 116–123.
- [9] Saba N, Alothman O, Almutairi Z, Jawaid M, Ghori WJ. Date palm reinforced epoxy composites: Tensile, impact and morphological properties. *J. Mater. Res. Technol.* 2019; 8: 3959–3969.
- [10] Nadhim A. Abdullah, Ahmed J. Mohammed , Ibrahim K. Ibrahim and Faise J. Mohammed," Study the effect of the adding of Ash of Palm Fronds on the Mechanical Properties for High Density Polyethylene (HDPE)", *Advances in Life Science and Technology*, Vol.66, 2018.
- [11] Nadhim A. Abdullah, Ahmed J. Mohammed, Ibrahim K. Ibrahim and Fayeze J. Mohammed," The Study of Effect of Adding Ash of Palm Fronds powder on the Mechanical Properties of Low Density of Polyethylene (LDPE)", *Journal of Aden University of Natural and Applied Sciences – Vol.26 (1)*, April, 2022.
- [12] Atiqah A., Jawaid M., , Sapuan S. M. and Ishak M. R., Mechanical and Thermal Properties of Sugar Palm Fiber Reinforced Thermoplastic Polyurethane Composites: Effect of Silane Treatment and Fiber Loading, *J. Renew. Mater.* Vol. 6, No. 5, August 2018, DOI: 10.7569/JRM.2017.634188.
- [13] Kabeel, Y. Rationalizing Energy Consumption by Improving Specifications of Some Heat Insulation Materials. Tishreen University, Lattakia City, Syria, 2009.
- [14] Zainab J. Sweah, Mohammed Ali jaber, Ahmed J. Mohammed, Study of mechanical properties behaviour of biodegradable blends based on wood adhesive, lactic acid, polyvinyl alcohol, and aloe Vera, *Materials Today: Proceedings* 42 ,2021, 2134–2140.